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Outlining a provident initial design approach with regard to cruise ship conversions

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Technology

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Abstract

A conversion describes the process in which a ship undergoes large modifications. For cruise ships, conversions are costly processes that often require drydocking and lengthy off-hire periods. There are many drivers that necessitate such large investments, including technical considerations such as a vessel's age or operational efficiency, as well as strategic ones such as market competition and revenue. Regardless of the reason, conversions demand large workloads, both in terms of the drydock process and the planning period beforehand.

The primary aim of this thesis is to investigate what can be done during a vessel's initial design stage to reduce the length, planning, and cost of future conversions. Ideally, recommendations should be straightforward, simple to implement, and cost-effective. By identifying potential initial design improvements, a provident approach is established for a ship's entire lifecycle.

In order to develop this outline, current conversion trends are studied at a broad, industry-wide and narrowed vessel level in order to identify today's conversion drivers and tasks. Using this information, four common conversion cases are selected as the foundation for the initial design solutions. These cases are broad enough to cover all relevant conversion tasks yet narrow enough to yield specific design solutions. A rules-based approach is then adopted to identify the technical challenges and initial design implications of each case, with a focus on SOLAS regulations. The cases are studied with respect to three disciplines, chosen due to their respective impacts on conversion processes. Namely, these are structural fire protection, means of escape and evacuation, and stability. Each discipline carries significant weight both in initial design and conversion engineering and the final recommendations therefore have broad influences.

The final list of initial design recommendations covers the three disciplines through arrangement principles and conservative margin allowances. Structural fire protection methods primarily focus on the classification of perimeter bulkhead and deck boundaries. Those for means of escape and evacuation are presented as both arrangement and margin solutions. The dimensioning of escape ways, lifesaving capacity, and evacuation routing are the bases for recommendations within this discipline. Finally, stability concerns are addressed through allowances and planning aimed at both the construction period and entire service life of a ship.

The thesis concludes with a case study and a discussion of the results and future implications of the research. The goal of the case study is to illustrate the methods identified and identify the prevalence and impact of the various conversion cases by considering a recently built cruise ship. The emphasis of the case study is on structural fire protection, since it is the most tangible of the three disciplines. The following discussion highlights the limitations and future considerations of both the study itself and the topic as a whole.

Keywords cruise ship, passenger ship, conversion, refurbishment, initial design, SOLAS

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Thank you.

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Acronyms and abbreviations

CCL	Carnival Cruise Lines
CLIA	Cruise Lines International Association
ECA	emission control area
EDG	emergency diesel generator
EPA	U.S. Environmental Protection Agency
FSS Code	International Code for Fire Safety Systems
FTP Code	International Code for application of Fire Test Procedures
GM	metacentric height
GT	gross tons
HVAC	heating, ventilation, and air conditioning
MGO	marine gas oil
IFO	intermediate fuel oil
IMO	International Maritime Organization
LSFO	low sulfur fuel oil
MARAD	U.S. Department of Transportation Maritime Administration
MARPOL	International Convention for the Prevention of Pollution from Ships
MSC	Mediterranean Shipping Company
MSC	Maritime Safety Committee (IMO)
NCL	Norwegian Cruise Line
NOx	nitrogen oxides
PM	fine particulate matter
ppm	parts per million
P&O	Peninsular and Oriental Steam Company
PVAG	Passenger Vessel Accessibility Guideline
RCCL	Royal Caribbean Cruises Ltd.
SOLAS	International Convention for the Safety of Life at Sea
SOx	sulfur oxides
USCG	United States Coast Guard
USD	U.S. dollar

1 Introduction

The purpose of this chapter is to introduce the main research ideas and provide the framework for the thesis. To accomplish this, an overview of the topic is first presented. Relevant scholarly works are then discussed after which an outline of the study is shown. The research problem, scope, and methods are identified to illustrate the aim of the thesis.

1.1 Topic overview

The current thesis focuses on cruise ship conversions. Generally, this describes major projects that physically alter a vessel. The term “conversion”, however, is difficult to define due to a lack of standardization throughout the industry. Other terms are often used interchangeably, depending on the source. These include “refurbishment”, “refit”, “remodel”, “renovation”, “makeover”, “relaunch”, and “revitalization”, among others.

In this work, a conversion refers to a project that is deeper in scope than the more basic refurbishment, though they often coincide with routine drydocking and maintenance work. In order to comply with regulations and contracts and ensure profitability, most cruise lines maintain docking intervals of two to five years for each of their ships [1]. During these routine maintenance projects, the work under the waterline is normally the focus [2], though the time out of service provides an opportunity to perform cosmetic upgrades as well. As such, typical refurbishments often include enhancements like new carpets, upholstery, furniture, and linens aimed at refreshing a vessel [3].

In contrast, a conversion is more closely described as a rebuilding [4] of at least some shipboard areas and features structural changes. This type of project requires a much higher degree of planning, as it is difficult to upgrade the physical characteristics of deck plans and hull design in retrospect [5]. Unsurprisingly, it is also much more expensive than a routine refurbishment. A typical drydock for a modern cruise ship costs 5-10 million USD while a more in-depth upgrade can easily cost in the range of 20-50 million USD or more [1]. Time is also a factor, as conversions cannot be completed in a regular drydock since longer periods, usually in weeks, are needed. Examples of structural changes undertaken in a conversion project include the addition of passenger cabins to existing or new spaces, the conversion of a seldom-used public space into a restaurant, or the addition of new deck areas or sections. A more detailed study into modern conversion projects is presented in the forthcoming chapters.

Within the topic, this thesis specifically studies potential conversion implications at the initial design stage, which here encompasses both basic and detail design for newbuilds. The former describes main outlines, arrangement, and hull characteristics while the latter delves deeper into detailed analyses of a vessel's structure and systems [6]. Final recommendations are aimed at both of these design phases, though further separation is not important. Instead, initial design is studied as a complete process and compared to future conversion planning, or conversion design and engineering. Hence, a ship's entire lifecycle, from design to operation, maintenance, and rebranding or retirement, is taken into account.

To complete this initial approach, current conversion trends are first identified by studying before and after plans of comparable vessels. The goal is to demonstrate how such projects could be simplified with better planning in the preliminary design phases. The hypothesis is that a more provident initial design that already considers likely future conversions will result in less complicated projects that save both time and money at later stages of a ship's lifecycle. This study is relevant in today's industry, as manifested by the increasing number and magnitude of conversion work being completed by every major cruise line.

1.2 Research problem and objectives

Many researchers have commented on the lack of scholarly work related to the cruise industry. Despite its rapid growth rate over the past decades, there is still an inadequate amount of academic research focused on this industry [7] and the existing research is limited in scope [8]. Past research has generally focused on two fields: marketing and revenue management [9]. The former is concerned primarily with passenger perception while the latter is aimed at maximizing the operating revenue of cruise ships. Such a limited range of research has resulted in a fragmented view on the industry and a corresponding research gap [10].

Existing works on refurbishments and conversions are even scarcer and less academic in nature. Aside from the occasional mention in industry reports and journal articles, the majority of reference literature on this topic stems from industry-related magazine articles and books. Cruise companies themselves emphasize renovations online and in marketing material, though on a small scale when compared to newbuilds. While these sources are informative and provide sufficient background information, academic research on the topic is warranted.

Finally, within ship design academia, more emphasis could be placed on farsighted design, or designing "for the future" by considering all phases of a ship's lifecycle. In this regard, most emphasis is placed on margins, particularly those related to weight and stability, as well as service life allowances, or future growth margins. Such an allowance should be considered in initial design so that future upgrades are feasible with acceptable impact. In practice, however, these are typically not included in commercial design [11]. Aside from margins, future considerations at the initial design stage are seldom stressed.

One aim of this thesis is to contribute to each of these areas. The documentation of conversion trends provides insight into the industry while the identification of initial design implications expands awareness of the importance of a provident design, all within the cruise ship context. More specifically, the main objective of the study is to outline an initial design approach that considers future conversions. The outcome should be a table compiled of current conversion challenges and their respective solutions. As such, the primary research question is framed:

"What can be done at the initial design stage to minimize conversion planning, length, and costs in the future?"

In order to answer this, certain sub-questions must first be considered. The first of these serves as a background question to identify the drivers and tasks of recent conversions. Though related, there is an important distinction between these terms. In this work, conversion "drivers" are the considerations influencing the decision-making process, or the reasons for conversions. Conversion "tasks", on the other hand, are the concrete changes that companies aim to complete during such projects. These together form the first sub-question:

"What are the major drivers and tasks in today's conversion projects?"

After the first phase, it is necessary to study what changes actually took place for selected projects. Once identified, the methods used to complete such alterations must be studied in order to specify potential improvements. The second sub-question therefore relates to the technical aspect of conversions:

"What regulations must be followed and what technical solutions are needed to complete the conversion tasks?"

The final sub-question seeks to tie the first two together in order to form the basis for the primary research question. Its aim is to determine whether improvements are possible by considering both conversion characteristics and technical solutions:

"Could the completed changes have been avoided or simplified through better planning at the initial design stage?"

Successively answering each of the sub-questions will provide the framework of the thesis and basis for its conclusions.

1.3 Research scope

One significant challenge in completing this study is defining an appropriate scope within the aforementioned topic. The focus must be small enough to complete with regard to given time and resource constraints while at the same time large enough to yield useful conclusions. This is difficult for cruise research due to the many varying aspects of the industry. These differences include the intended market, which varies based on a cruise line's sophistication level. Generally, there are four identified market segments, with contemporary, premium, luxury, and expedition ships each catering to different groups [12]. The same is true for the operating region of a ship, as there are numerous variations in preferences across different countries and cultures [13]. In fact, in the cruise industry, a vacationer's country of origin has stronger effects than the cruise brand on consumers' evaluation of quality [9]. These are only two examples, however, and additional differences are dependent on cruise length, time of year, and ship size.

With these differences, it can be difficult to reach a conclusion that has far-reaching implications and the chosen research scope must always be remembered. For this study, that scope centers on the contemporary U.S. cruise market. Though this market has recently seen a decline in its share of global cruise activity [14], it is still the largest in the world and has the highest share of both passengers [15] and large, contemporary cruise ships . Such ships are the focus of this study since they are generally the ones that undergo the largest and most complex conversion projects. Figure 1.1 shows that the vast majority of vessels carrying over 2000 passengers currently serve the U.S. market.

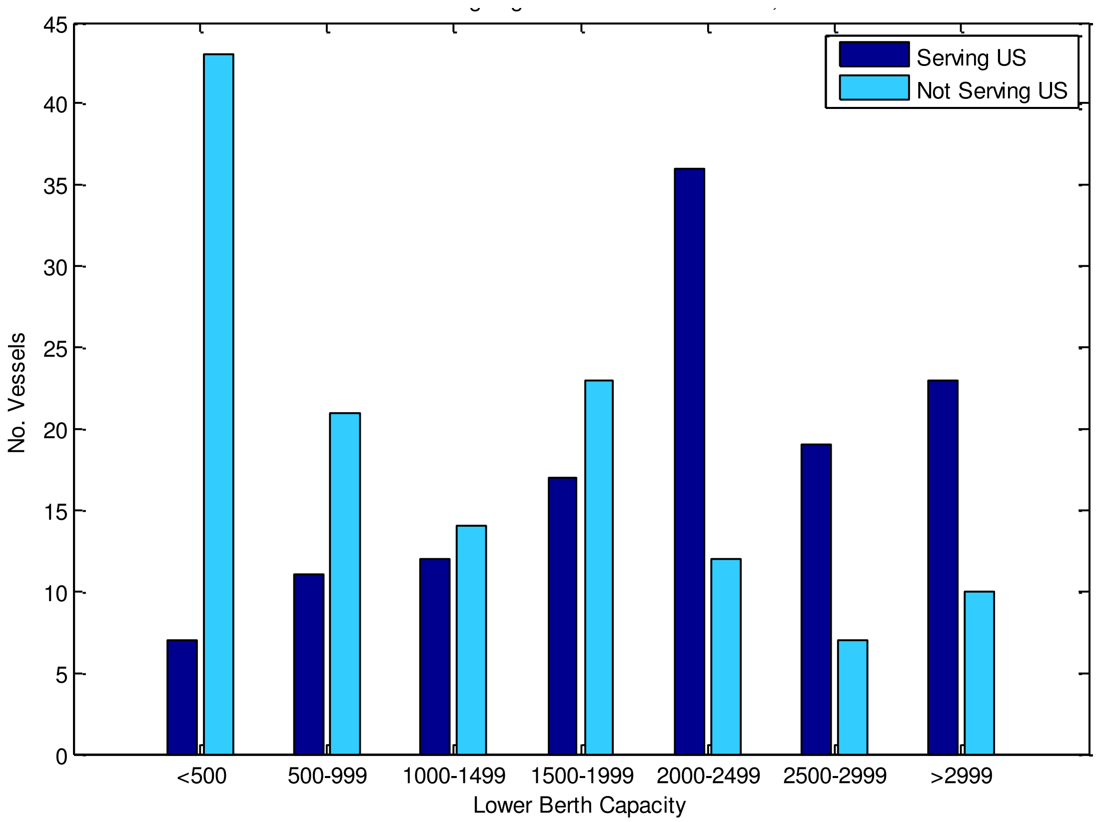

Figure 1.1. Global ocean-going fleet size profile, 2013
Source: adapted from [12]

The core research is further narrowed to three specific cruise ships that fall within this market segment. This allows for a detailed look into recent projects. The three vessels are chosen based on their similar operating profiles, ages, and conversion dates. Each is operated by a different cruise line, however, and differences between the projects give further insight to the market as a whole.

Though the scope is limited to the U.S. contemporary market and further concentrated on three cruise ships, some findings can be generalized to allow for broader implications across different markets. Even with major differences, innovations and trends in cruise ship design are increasingly global and not at a purely regional level [16] and certain conclusions should be valid across varying segments as well.

1.4 Research methods

The basic structure of the thesis is divided into three key parts. Namely, these are the background study, identification of current conversion trends, and outlining of initial design implications and recommendations.

The background study is completed with a literature review and statistical analysis. The literature review is conducted to give insight into the overarching themes of the topic and is presented at a hierarchical level. First, the general cruise industry is studied in order to highlight current challenges and trends that validate the need for research on the proposed topic. A deeper look into the U.S. contemporary market is then provided, corresponding with the scope of the thesis. Finally, an overview of cruise ship conversions gives perspective on the importance and magnitude of such projects. In addition to this review, statistical analysis is intermittingly presented for support. Various sources of data are used in this regard, including ship specifications and market analyses. The largest and most useful source is the *North America Cruise Detail Data* database published by MARAD [17], from which generalizations are formed for the U.S. market.

The final two parts are completed with the same types of methods. Again, existing literature proves useful, especially in the selection of important conversion drivers. More emphasis, however, is placed on statistical analysis, this time in relation to fleet characteristics of the major cruise lines in operation. One particular use is to portray average fleet ages of various lines over time in order to show the need for conversions. Following the identification of trends, a review of reference cruise ships is completed to allow for detailed insight into such projects as well as comparisons between them. Concurrent with this is a technical review to identify the engineering principles used. Rules-based considerations are taken into account in addition to vessel specifications and arrangements. This review is crucial, as meaningful insight cannot be garnered without studying conversions at a technical level.

1.4.1 Data collection

An extensive database of fleet characteristics was created for the top cruise lines based on passenger capacity. For each line, all commissioned vessels are listed along with corresponding capacities, gross tonnage, and delivery year. This information is shown per annum from 1966 to 2016, though the final two years are based on forecasts. The analyzed data allows for statistics including average fleet ages over time.

For ships still in operation, the Complete Guide to Cruising & Cruise Ships 2013 [12] and *North America Cruise Detail Data* set [17] are the main sources. Capacity information, where available, is taken from the latter while the remaining capacity, age, and tonnage data from the former. For vessels no longer under commission, data is taken from various sources, including reference books, company websites, and additional online sources. Though vessel ages are readily accessible, the capacity and tonnage figures of the early-era ships are less reliable. Additional factors should also be considered, such as the fact that, in reality, a ship's gross tonnage and capacity may change over its lifespan due to conversions. With this in mind, it is the average fleet ages that are primarily used in this work.

Relevant parts of the resulting database are provided in Appendix A. Figures generated from collected data include a reference to the appendix in order to differentiate those based on published work, as both types are generated in MATLAB. It is difficult to present precise data on the cruise industry due to its fast pace and a lack of easily accessible data, though primary sources are accurate to a high degree. CLIA data, for instance, captures 95% of the global cruise capacity [18] while MARAD statistics are estimated to cover over 97% of cruises for the U.S. market [19]. The compiled data is limited to ships over 1000 gross tons and does not include cruise ferries, river cruise ships, floating hotels, or ships operating as casinos [20].

1.5 Thesis structure

The thesis is organized into six main sections, as outlined in Figure 1.2. The second of the sections, identifying conversion trends, is covered over two chapters due tits extent.

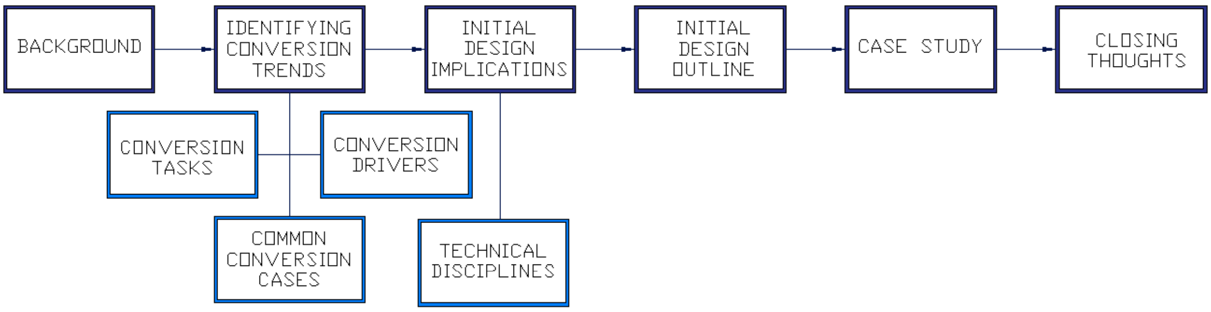

Figure 1.2. Basic structure of the study

The structure follows a systematic approach with regard to each section's scope. The background is extensive, covering the history and characteristics of the cruise industry and conversions. The identification of conversion drivers is slightly more narrowed though still presented with respect to the contemporary market. This is followed by the identification of conversion tasks and cases through the review of three ships. Initial design implications are then presented before considering a case study for a single ship. The thesis concludes with a generalized discussion on the findings and future implications of the research.

1.6 Summary

The broad topic for the current thesis concerns cruise ship conversions, which are defined as major renovation projects featuring structural changes to at least some shipboard areas. Such a study is warranted due to a lack of existing literature as well as a growing demand for such projects in today's industry.

The goal of the study is to outline an initial design approach that considers future conversions in order to save time and money during the later stages of a ship's lifecycle. In order to meet constraints, the research scope is limited to the contemporary U.S. cruise market, though generalizations for other segments are considered. The primary methods used throughout the thesis are literature reviews, statistical analyses, case studies, and technical reviews.

2 Background

This chapter provides background information for the study. There are three main sections presented, the first of which focuses on cruising in general and the cruise industry as a whole. Following this, the contemporary U.S. cruise market is analyzed to reflect the specific scope of the thesis. The final section provides an overview of cruise ship conversions. The purpose is to allow for a better understanding of the topic on both a narrow and broad level.

2.1 The global cruise industry

A cruise today is defined as a dual vacation and voyage that is normally taken to relax in comfortable surroundings [12]. Often, though not always, a ship departs and returns from the same port of embarkation and visits several destinations over varying lengths of time. Since its inception, the industry has overcome many obstacles and has constantly evolved over time.

2.1.1 A brief history

Modern cruising has a history spanning back to the early nineteenth century, where the British are accredited with its origin. The Thomas Cook Travel and Tour Company is generally acknowledged as the first to arrange escorted group excursions by sea, as early as 1841, while P&O organized purely recreational voyages starting in 1843. These voyages were conducted on dual-purpose coastal cargo steamers, however, and the first ship specifically designed for such voyages, the German ship *Prinzessin Victoria Luise*, was not delivered until 1900 [21].

Cruising continued throughout the following decades, though largely as an afterthought of passenger liner service. Its development grew out of the need to gain off-season revenue from ocean liners that would otherwise be laid up [22]. It wasn't until the rise of the jet age and subsequent collapse of ocean travel that modern cruising took form. Like the British before them, it was now the Norwegians who pioneered this new era, starting with the delivery of Norwegian Caribbean Line's *Sunward* in 1966 [23].

The immediate success of early cruise ships resulted in what has been described as the greatest repositioning of any product in history [5]. Former ocean liners changed roles completely and the industry was repositioned as a mass market product for the first time [16]. Following this success, the first purpose-built modern cruise ships were introduced for Royal Caribbean Cruise Line. Again of Norwegian origin, these vessels were completed in the early

1970's and represented the first newbuilds that were neither intended for liner service nor based on a ferry design [24]. The final major milestone during this busy period was the introduction of Carnival Cruise Line in 1972. By marketing their ships and not ports as the holiday destination, Carnival created the mass market cruise holiday that survives today [13].

2.1.2 Industry growth and demand

Following challenging early years, cruising has enjoyed relentless growth on its way to becoming the fastest-growing segment in the leisure travel market [15]. The 1980's were highlighted by growing success despite a low number of newbuild projects, though this changed drastically in the 1990's with the introduction of custom-built mega ships. The next two decades saw a surge in newbuild projects, with an increase of commissioned vessels from 40 to nearly 200 in response to cruising's increased popularity [25]. With new tonnage came new passengers and the industry today has demonstrated a 7.2% per annum growth rate since 1980 [15] and a 7% growth rate since 1990 [26], as illustrated in Figure 2.1.

This steadily increasing passenger load has been facilitated by a parallel increase in cruise ship size, as shown in Figure 2.2. Today, larger ships are preferred due to economies of scale, which is a principle arguing for a reduced number of crew per passenger [27]. This principle, along with shipbuilding costs, has yielded a popular size of around 140,000 GRT, or about 3,500 passengers, for today's contemporary cruise ships [12]. When the first cruise ship over 100,000 gross tons, *Carnival Destiny*, was built in 1996, many believed that the size of the largest ships had largely peaked [28]. Today, however, the largest ships are over twice the size of the *Destiny* and 17 of the 23 ships scheduled for delivery through 2016 will exceed 100,000 gross tons [26]. As it stands, ships exceeding this tonnage make up 37% of the global fleet capacity [29].

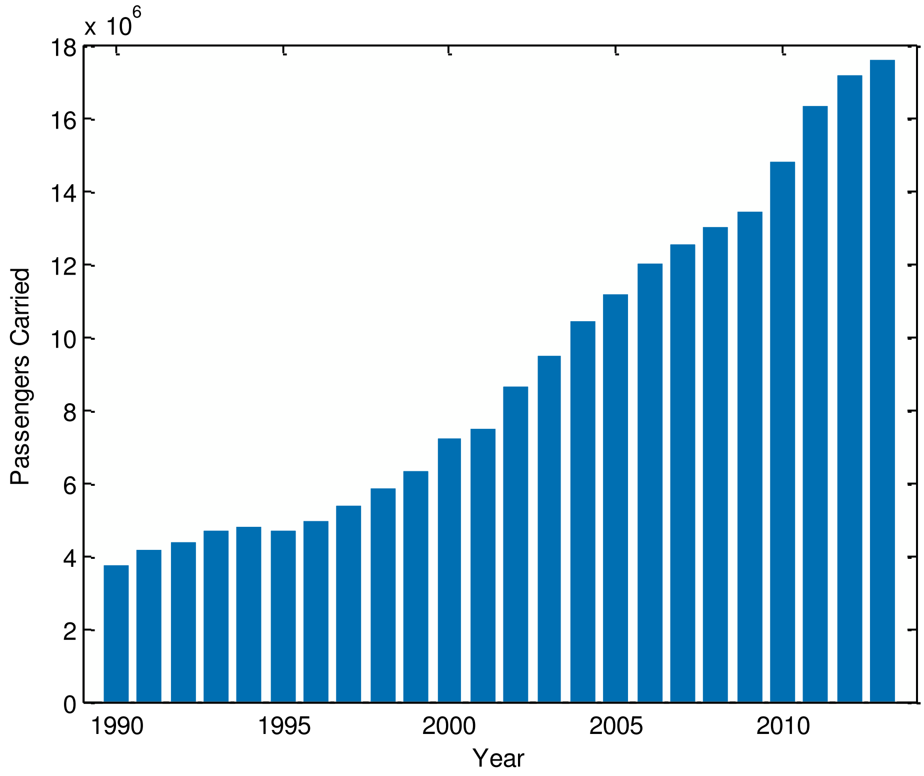

Figure 2.1. Passenger trends over time, CLIA members

Source: adapted from [30] and [31]

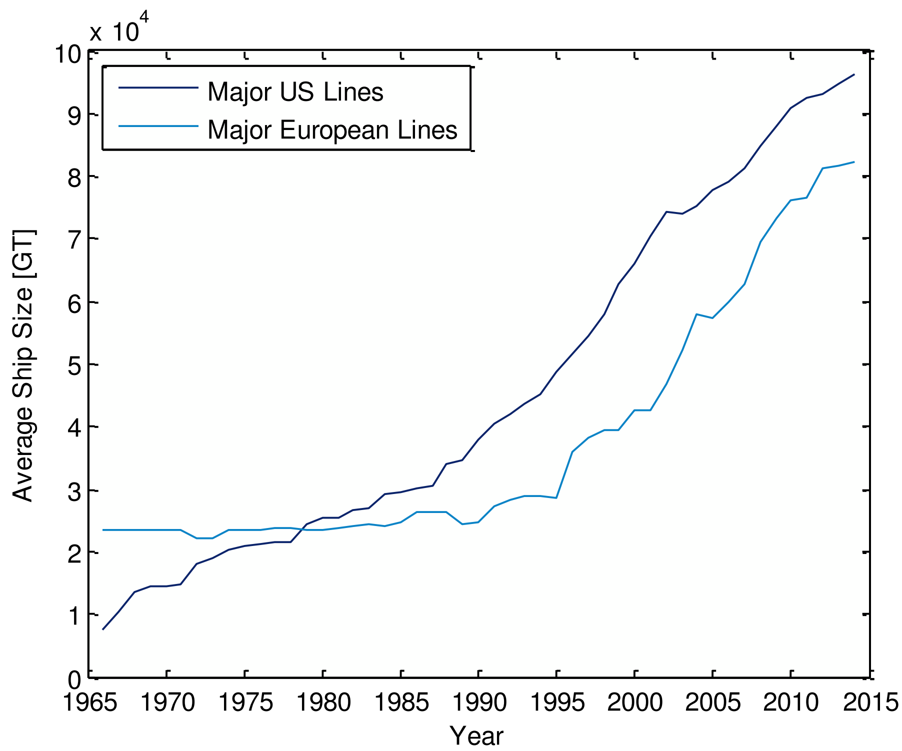

Figure 2.2. Average ship size over time

Source: adapted from Appendix A

The growing size of modern ships demonstrates the propensity for the major cruise lines to increase capacity in order to meet consumer needs. On the demand side of the industry, there is little inclination that such needs will change in the future. Current trends portray an increased interest in cruising and an industry in which demand continues to outstrip supply in terms of double occupancy figures [15]. This has already been the case for over a decade, as the ratio of carried passengers to double occupancy has been over 100% since 2003 [9]. In the years to come, continued growth will largely stem from repeat passengers, as over 85% of U.S. customers have cruised before [32]. Since the industry today yields the highest satisfaction rating of any vacation sector [33], the tendency of repeat passengers to fuel market growth should continue unabated.

2.1.3 Structure of today's industry

Over time and especially since 2003, the cruise industry has become an oligopoly. According to industry estimates [34], the largest ten cruise brands control 77% of the global capacity, as illustrated in Figure 2.3. The remaining 23% is divided across 41 different brands, showing a large disconnect. In terms of newbuilds, there is an even larger disparity, with 89% of new capacity being delivered to the top ten brands over the previous five years [29].

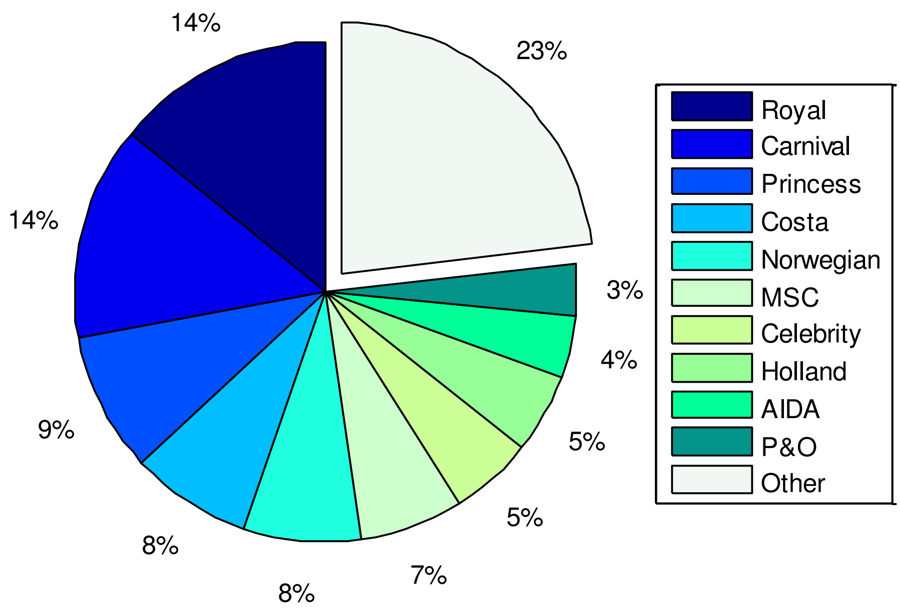

Figure 2.3. Cruise brands by capacity, 2014

Source: adapted from [34]

Of the major cruise lines, six are based in the U.S. while the remaining four are European. Eight of ten are classified as contemporary lines and two as premium [12]. Of the global capacity, over 80% originates from contemporary brands. This highlights the dominance of this market when compared to the 14% share of premium capacity and the 4% share of luxury and niche capacities combined [34].

Figure 2.4 shows that the industry is even more concentrated at a corporate ownership level, where nearly 90% of the global capacity is traced to only four conglomerates. Carnival Corporation is by far the most dominant player, operating 105 vessels that contribute to nearly half of the total market share. Royal Caribbean Cruises Ltd. is the closest competitor even though its combined fleet is less than half the size of its main rival. RCCL's flagship brand, Royal Caribbean International, is now the largest operator at a brand level, however (Figure 2.3). It should be noted that the Royal Caribbean figure includes TUI Cruises, which is a joint venture with TUI AG. The same is true for the third largest publicly traded company, Norwegian Cruise Line, which is partly owned by larger conglomerates like Genting Hong Kong and Apollo Management [34].

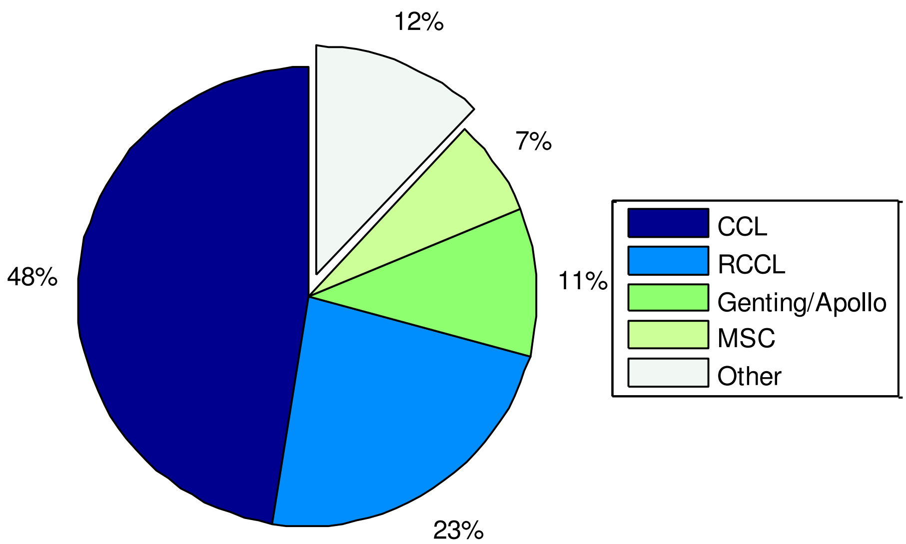

Figure 2.4. Corporate ownership by capacity, 2014

Source: adapted from [34]

2.2 The contemporary U.S. cruise market

As covered in Chapter 1, the focus for this study is on ships belonging to the contemporary U.S. cruise market. This market is generally where the largest ships operate (Figure 1.1) and the one featuring the most complex conversion projects. Another motive to study this market is its continued dominance in terms of deployment and market share. Though some developing markets have shown higher growth percentages in recent years, North America remains the world's largest cruise market with a 55% passenger source share [35].

Of the destinations regularly served from North America, the Caribbean and Bahamas remain to be the most visited in the world. Even with recent challenges, the region saw a 12% deployment increase in 2014 and still accounts for nearly 40% of the global capacity [35]. North American voyages also show the highest worldwide demand as a measure of occupancy rate, with an average rate of approximately 110% [17]. It can be expected for this demand to increase in the coming years, as evidenced by the upward trend shown in Figure 2.5. This will largely be driven by strong market potential, as less than 20% of the U.S. population has taken a cruise vacation [9].

Within the U.S. market, contemporary vessels dominate in both deployment and demand. Between 2004 and 2012, contemporary cruises made up 69% of total U.S. cruise vacations taken. They showed an average occupancy rate of 113%, with 92% of all voyages sailing at over-occupancy levels [17]. This is in stark contrast to the other sectors, as premium, ultra-premium, and luxury lines showed only 70%, 12%, and 5% over-occupancy percentages for the same period, as shown in Figure 2.6.

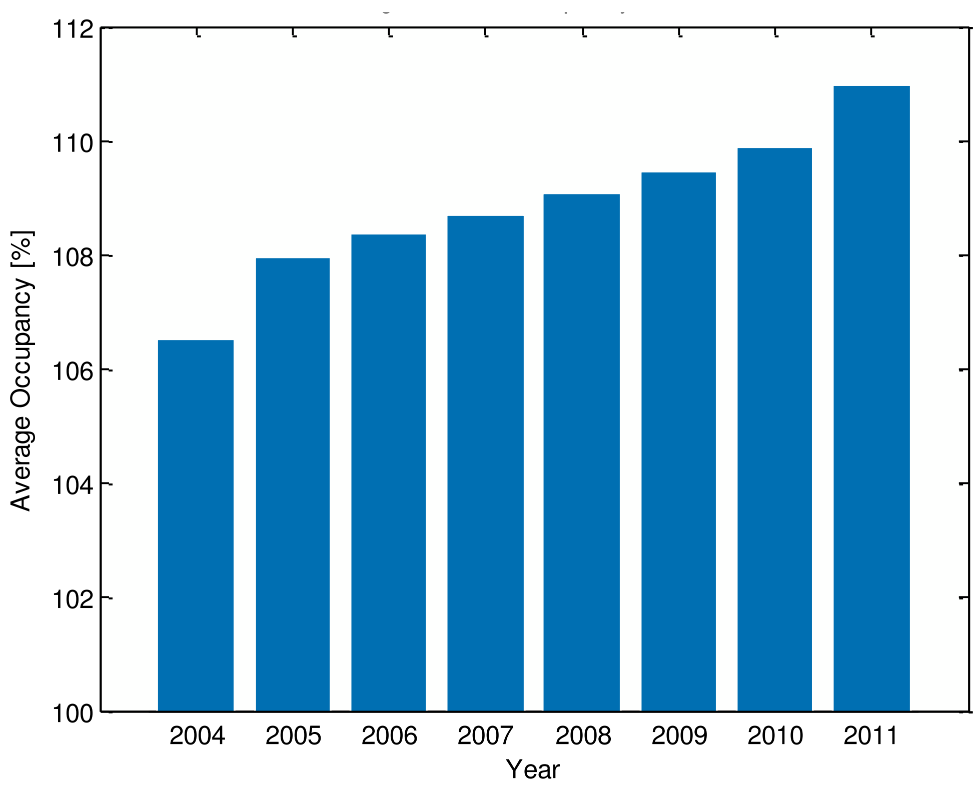

Figure 2.5. Average U.S. market occupancy over time

Source: adapted from [17]

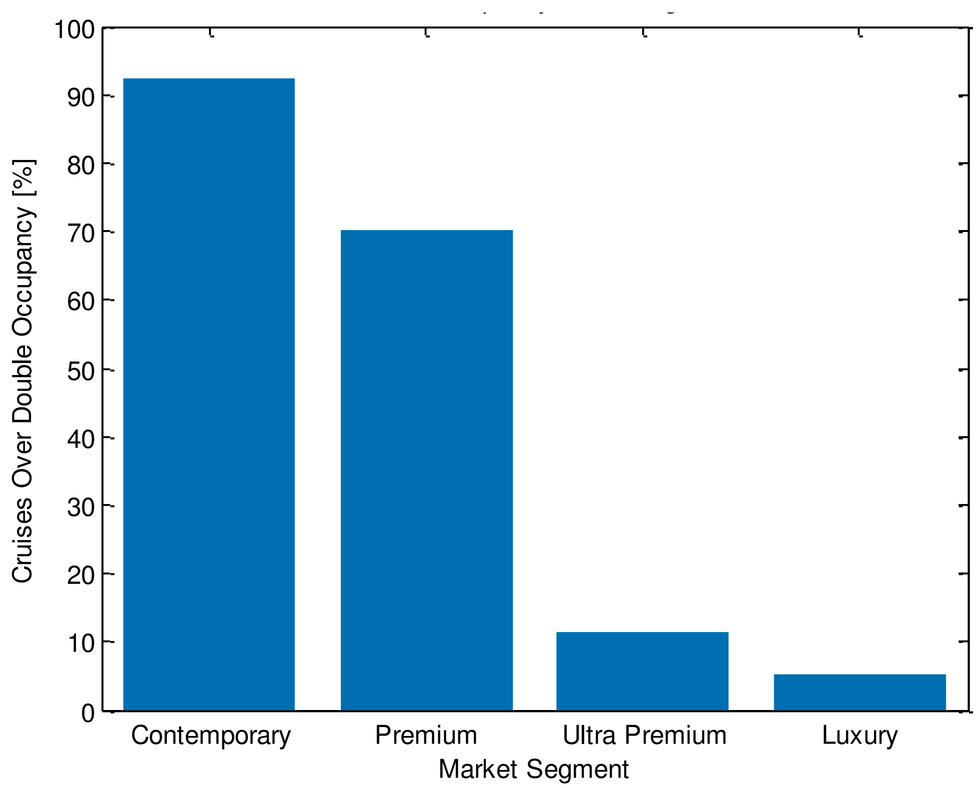

Figure 2.6. Average over-occupancy percentage by market segment

Source: adapted from [17]

2.3 Recent industry challenges

While the success of the cruise industry is evident and future growth expected, it would be remiss to neglect the rising challenges facing the industry. In contrast to the rapid expansion of the late 1990's and early 2000's, the past five years have been turbulent. Numerous successive setbacks have caused this and even the largest two corporations have struggled to improve or even maintain the financial success experienced before. Figure 2.7 illustrates these difficulties as a plot of net income over the past decade.

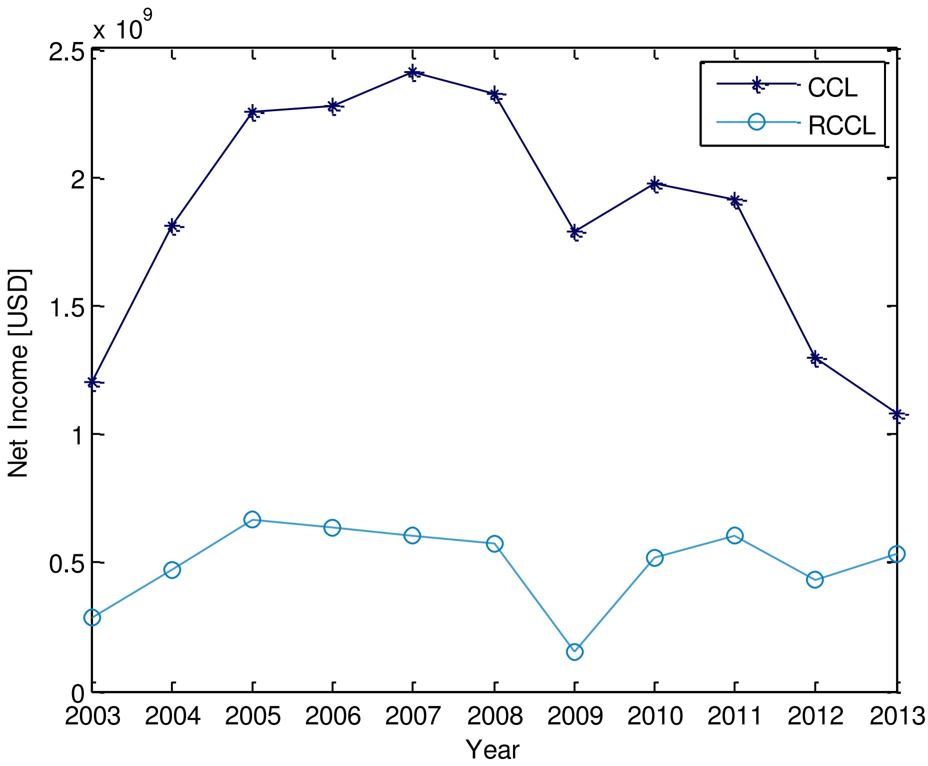

Figure 2.7. Financial profiles of the two major cruise corporations
Source: adapted from [36] and [37]

In addition to the downward trend since 2008, the similarity between the two plots demonstrates the industry's interconnected nature. Two noticeable declines occur after the 2008 and 2011 operating years. The first is attributed to the global recession and financial crisis of 2008 and 2009 [8] that resulted in the first decline in spending by cruise passengers [38]. The next was more unpredictable, as it resulted from industry accidents. Though numerous events have made headlines over recent years, the partial foundering of *Costa Concordia* was the most detrimental. The accident occurred in January 2012, a crucial booking period, and reservations for the year declined immediately [12]. A second event occurred nearly a year later, when an engine room fire left the *Carnival Triumph* stranded in the Gulf of Mexico. Though not as serious as the *Concordia* tragedy, the media attention was severe. According to RCCL's CEO, it was this adverse media coverage that caused a disruption to demand in the U.S. [39]. Both the *Concordia* and the *Triumph* were owned by Carnival Cruise Lines and the latter event seems to have affected Carnival more than RCL, as implied by the latter's resurgence in 2013. Still, the overall trends of Figure 2.7 show that negative effects reach beyond a corporate level.

Along with these events, additional issues have challenged the industry. Namely, fuel considerations and factors inherent to the industry's structure are formidable. Today's main challenges are therefore related to economics, media coverage, fuel, and inherent factors.

2.3.1 Economic and political considerations

Of the identified challenges, the ongoing economic crisis is the most measurable, as seen in the recent decline in newbuilds. It is misleading to represent the newbuild rate in terms of ships due to their increasing size over time (Figure 2.2). Figure 2.8, which shows the general trend of new ships over time, is therefore presented as a measure of gross tonnage.

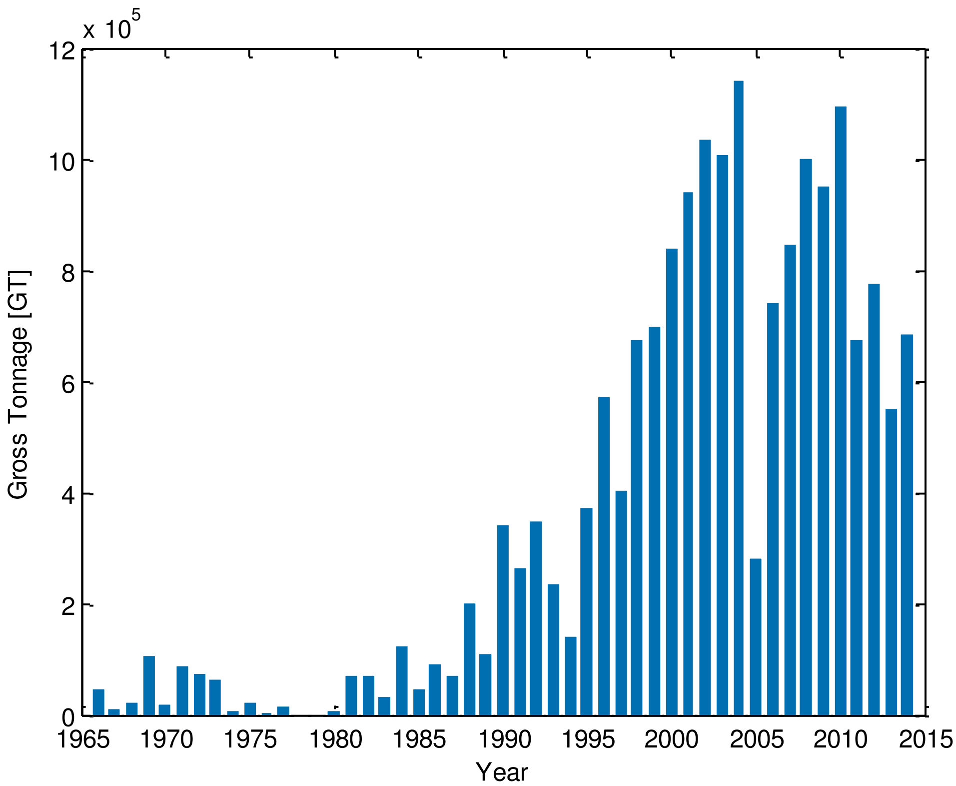

Figure 2.8. Global ocean-going cruise ship newbuilds over time

Source: adapted from Appendix A

Various conclusions can be drawn from Figure 2.8 and, though disturbances exist, an overall trend is visible for recent years. Unsurprisingly, the past five years have been defined by a much lower development level when compared to the "peak period" of the early 2000's. As seen in the figure, this recent decline began in 2011, which is tied to the 2008 economic downturn, as new cruise ships are ordered several years in advance. This crisis, along with mutual political unrest in many parts of the world, caused a significant slowdown in orders across the industry [25] and a rebound has still not taken place. The number of vessels on order through the final quarter of 2015 is only half of those prior to the crisis [40] and the current capacity growth for the major lines has fallen from nearly 15% to less than 5% [41].

The recessions' effect on the industry has been compounded by a parallel increase in shipbuilding costs due to higher steel and labor prices as well as increased banking fees charged for lending money used for construction and shipbuilding guarantees [12]. This trend has somewhat backtracked over the past year, however, as shipyards have begun offering bids featuring a reduced price for a ship similar to a previous order, resulting in a five-year low in terms of building costs [41]. This has worked, as there is currently a much-needed surge in newbuild announcements from the largest operators.

2.3.2 Accidents and media coverage

The impact of the economic recession has been severe and long lasting, though easier to predict and prepare for than the accidents that have recently plagued the industry. As mentioned, both the *Costa Concordia* and *Carnival Triumph* mishaps resulted in direct losses in the form of reduced bookings [12], [39]. The effect of such incidents is not easy to quantify, though the amount of negative press has been a hindrance. In addition to the aforementioned accidents, media coverage of onboard fires, excursion accidents, lost and drowned passengers, and gastrointestinal outbreaks have affected the industry's reputation [38]. The most direct effect of such negative press is on bookings, though they can also cause unforeseen consequences. The price of insuring cruise ships, for instance, increased after *Costa Concordia*'s loss [12].

2.3.3 Fuel and environmental considerations

Economic volatility and accidents are characterized by their uncertainty. This differs from environmental and fuel concerns, as cruise lines have been planning for existing and imposing environmental regulations for many years. Coupled with high and rising fuel prices, this has become the single biggest threat to today's cruise industry [25].

Fuel regulations came to the forefront of the industry in 2005, when IMO MARPOL Annex VI, Regulations for the Prevention of Air Pollution from Ships, became mandatory. This was followed by a revision in 2008 that introduced mandatory emission limitations on ocean-going vessels, including more stringent limits for those operating in emission control areas (ECAs) [42]. Currently, there are four IMO-designated ECAs. The Baltic Sea (2006) and North Sea and English Channel (2007) ECAs were first formed to limit sulfur oxide emissions (SOx) followed by the North America (2010) and U.S. Caribbean Sea (2011) ECAs [43]. The latter two introduced stricter control by limiting nitrogen oxides (NOx) and particulate matter (PM2.5) in addition to SOx. Existing ECAs are shown in Figure 2.9, along with areas that may apply for designation in the near future.

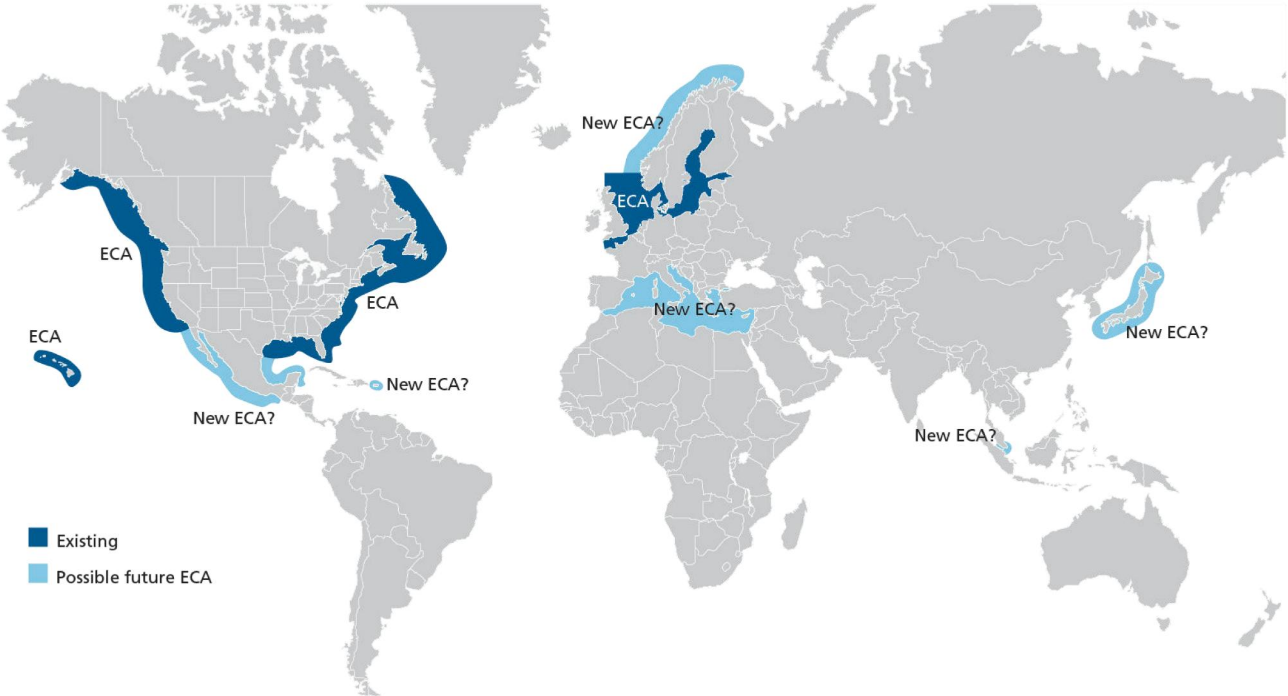

Figure 2.9. Current and potential ECA designations
Source: [44]

Of the targeted emissions, SOx are commanding most attention. Whereas NOx emissions are influenced by engine design and operation, SOx emissions are dependent on the consumption of fuel [42]. As a result, NOx targets are aimed at future newbuilds while those for SOx are retroactive. It is expected for ships to meet sulfur limits by operating with better quality fuel oil, distillate, though operators may equip vessels with exhaust cleaning devices that extract sulfur from exhaust as an alternative [45]. NOx emissions will be controlled with the use of high efficiency aftertreatment technology or new, compliant engines.

Since its inception, SOx standards in ECAs were limited from 15,000 ppm (1.5%) to 10,000 ppm (1.0%) in 2010 and a further reduction to 1,000 ppm (0.1%) will be imposed in January 2015. A global standard of 5,000 ppm (0.5%) will come into effect in 2020 at the earliest and no later than 2025 [46]. These limits are shown graphically in Figure 2.10, where the dashed line represents a possible extension that is dependent on a 2018 review.

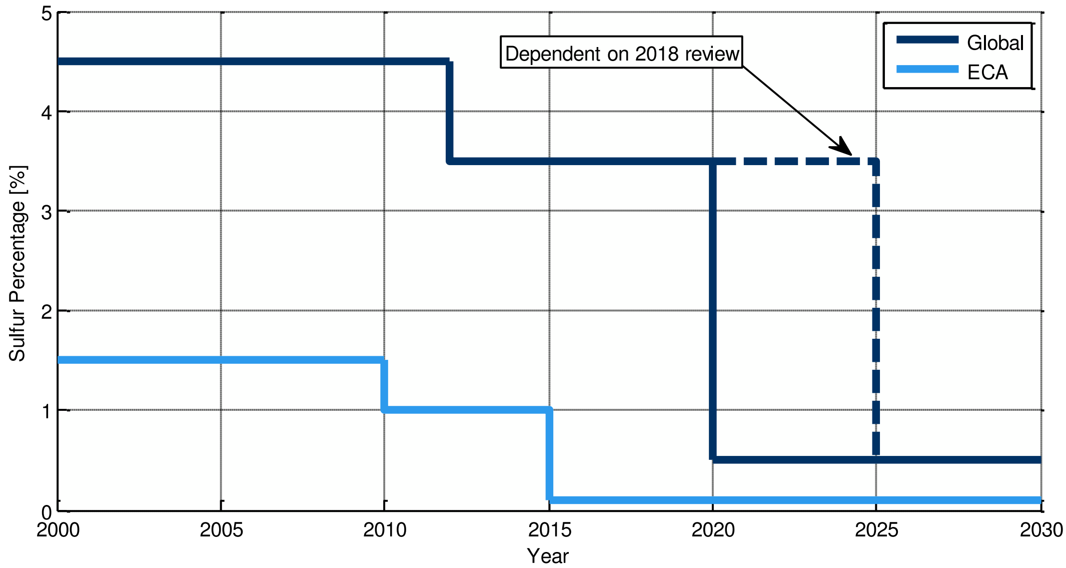

Figure 2.10. MARPOL Annex VI SOx emission control limits

Source: based on [43]

For some new ships, the Energy Efficiency Design Index must now be followed to reduce carbon dioxide (CO2) emissions and improve efficiency, though passenger ships are not yet targeted. NOx emission limits are also being lowered, in stages. Tier I stipulated a 15% to 20% NOx reduction for existing engines while Tier II demanded a 20% reduction for new ones. Tier III will push savings to 80% when introduced in 2016 [46] or 2021 if an amendment is accepted [47]. Tier I and Tier II are global regulations while Tier III applies only to ECAs.

By 2020, MARPOL's Annex VI is expected to reduce ECA NOx, PM2.5, and SOx emissions by 23%, 74%, and 86%, respectively [45], though this will come at a large price to operators. Fuel is already the largest single cost for cruise operators, often representing around 20% [48] or even half [49] of total operating costs . With low sulfur fuel, however, costs would greatly increase. Such fuel is a distillate product which involves an expensive desulfurization process [49] and the result is an increase of up to 25% or 95% from IFO to LSFO or MGO, respectively. For shipping as a whole, fuel costs are predicted to potentially increase by up to 63%, depending on price development and the use of advanced technology [50].

Because of these regulations, many cruise lines have invested heavily in technology and research aimed at reducing fuel costs. Carnival Corporation followed several others in applying for flexibility to IMO by supporting the development of exhaust gas cleaning technology to meet emission requirements at a lower cost than using low sulfur fuel [47]. Norwegian Cruise Line became the first to install scrubbers with the retrofit of *Pride of America*, which operates entirely within Hawaii's ECA [51] while Royal Caribbean will introduce the technology in the form of four hybrid exhaust gas scrubber systems on their newest ships [39]. Carnival, Royal Caribbean, and Norwegian Cruise Line have many installations planned in the coming years.

The North American ECA is currently of the most concern due to the number of ships originating from the U.S. Alaska and Canada/New England cruises are especially affected, as 100% of the distance traveled can lie within this ECA. Cruises originating in Atlantic states are also in focus, as the same figure can reach 60% [26]. This has the potential to fortify growth in other markets, including Asia, where ships may operate in waters not governed by ECA restrictions.

In addition to investing in technological solutions, cruise lines have emphasized operational efficiency in order to reduce fuel consumption. The main changes have been to itineraries. By reducing the sailing distance and port times, ships are able to travel more slowly and consume less fuel and this has been a focus of the major lines [52]. Other simple operational changes like trim optimization further increase savings [53], though operators have still been forced to resort to drastic measures. Carnival Cruise Lines, for instance, repositioned two of its ships from mid-Atlantic ports in order to limit the distance traveled within the ECA [51], while others may implement fuel surcharges in order to offset costs [48].

While the highlighted regulatory changes have the potential to benefit the environment and welfare of those living within ECA borders, they have introduced major challenges to the cruise industry. Even with investments and operational changes, many markets will likely diminish and operators may find it difficult to reap desired profits. The upcoming deadlines will mark the most stringent restrictions under MARPOL's Annex VI and lines have been forced to change their focus in order to meet them.

2.3.4 Inherent growth challenges

The previous three challenges have been easy to define. In contrast, additional factors affecting the industry are inherent to its growth and as such are unavoidable. Specifically, researchers suggest that the industry has entered a maturing phase in which passenger numbers are still increasing but at a declining rate [8]. In essence, this is a stage where the growth of the past can no longer be sustained. The indicators of a maturation stage are globalization and contraction [54], both of which are present in today's industry.

Contraction is present in terms of ownership, as illustrated in Figure 2.3 and Figure 2.4. The concentrated nature of today's industry has made it increasingly difficult for cruise lines to gain market share. As a result, contemporary lines have begun to rely on value pricing, where additional revenues must be generated onboard to increase profits [55]. This is evident for the major cruise lines, where onboard revenue is now the main driver of industry growth. In fact, without onboard revenue, Carnival Cruise Line would generate no earnings before interest and Royal Caribbean International would incur an operating loss [56]. Because of this, tickets are no longer sold as an end but rather as a means to generate revenue onboard.

The second identifier of the industry's maturation, globalization, is also evident. This has occurred through expansion into new markets through operating alliances, mergers and takeovers [54]. Such expansion has been one of the major trends over recent years, with many sectors experiencing drastic deployment and market share increases. Growth in Australia and Asia has been especially strong, with deployed capacity increases of 155% and 302% over the past five years, respectively [31]. In particular, much emphasis will be placed on China in the coming years, as that market will continue to be the primary source of development in the region [57], bolstering Asia's status as the world leader in international tourism growth [31]. As a whole, the Asian market source is expected to quadruple to seven million passengers by 2020, increasing its market share from the current 7% to 20% globally [58]. Globalization of the industry will broaden with time, as many countries show low market penetration along with growing economies, disposable incomes, and middle classes eager to cruise [59]. Today's larger ships also offer greater economies of scale which facilitate lower cruise prices that in turn open up new markets [60].

The cruise industry's contraction and globalization imply that a maturation stage has already been reached. Increasing net profits is therefore more challenging and larger amounts of capital are needed to maintain growth [26]. As such, it is no longer probable for the industry to experience the high annual growth rates of the previous decade, even without the aforementioned challenges.

2.3.5 Looking forward

The cruise industry is facing many challenges. Those identified, however, have widespread influence and are affecting all industries [49], including others within the global tourism umbrella. Still, as summarized in section 2.1.2 of this chapter, forecasts predict future industry growth, including an expected 2% global increase over the next year [61]. While this represents a lower growth rate in comparison to the past, it is nonetheless a promising sign given the ongoing economic recovery.

High satisfaction ratings, repeat passenger statistics, and recent newbuild announcements are also optimistic indicators, as is the industry's proven resilience over its history. The industry has overcome similar setbacks before, from accidents to worldwide crises. Following the events of September 11, for instance, cruise bookings declined drastically but rebounded in time to post record results by the end of 2002 [16]. This resilience, along with a strong product value, low market penetration, innovation, and global growth potential, offers a positive outlook [29].

2.4 Cruise ship conversions

Conversions have been intertwined with cruise ships over their entire history since being first completed for early cruise yacht adaptations. The intentions of these projects have evolved along with the technological advances used to complete them. Similarities are still present, however, and conversions will play as important a role in the future as they have in the present and distant past.

2.4.1 A brief history

The first cruise ship conversion dates back at least to the early 20th century, when P&O converted one of their liners into the cruise yacht *Vectis* in 1904 [21], a trend that continued throughout the century. Such early conversions featured simple and direct changes that were in line with the generation's shipbuilding capabilities. Common examples included the addition of cabins in cargo spaces or an on-deck pool. It was not until the 1950's, when many liners were pulled out of service, that sophisticated conversions became common practice [4].

During this period, conversions of ocean liners like *SS France* and *Queen Elizabeth 2* took precedence. As built, such vessels were not profitable in cruising service, due in part to high passenger-space ratios and redundant onboard areas. Conversions including both space reconfiguration and technical improvements therefore spared them from premature scrapping by rendering them as highly competitive full-time cruise ships [4]. There have been various other extreme examples since. Costa Crociere, for example, converted two RO-RO container ships into cruise vessels in the late 1980's, one of which was designed for the European market and the other for Americans [4]. Conversion projects for purpose-built cruise ships began soon after their completion. *Song of Norway*, for instance, was the first cruise ship to be "stretched" by inserting a midsection in 1977, only seven years after her delivery [27]. Since then, conversion projects have only increased in both number and scale.

2.4.2 Modern conversions

Early conversions differed in that vessels commonly emerged with new service types, though they share common purposes with modern ones. As before, profitability is the primary driver of every decision and the goals of today's conversions are in that way similar. Because of technological advances, modern conversion projects are much more complex, expensive, and common than their predecessors. Much like newbuilds, there is now a competitive market for ship upgrades, with major cruise lines being forced to refurbish multiple vessels each year in order to keep pace [62]. The majority of work completed is through minor refurbishment and updating, though there has been a surge in large conversion projects. The Grand Bahama Shipyard, for instance, oversaw nineteen cruise ship drydocks in 2012. Of these, twelve were for minor public space improvements, four for upgrades to public spaces, and three for major reconfiguration of public spaces and addition of new cabins [1].

The most extensive recent conversions have included the addition partial decks and midship sections. Though cruise ship "stretches" are not common due to their long off-hire times, there have been three ships stretched since 2005 [63], [64] and another four with similarly planned projects over the next two years [65]. With regard to price, conversions are expensive. Typical refit costs run at around $2 million USD per day and are rising due to material, equipment, and labor costs [12], along with tighter project schedules. Still, cruise lines are willing to pay for them. Celebrity Cruises recently completed a $140 million USD conversion program on four of their vessels while Royal Caribbean is currently upgrading its fleet at a cost of $300 million USD [66], for example.

With the ongoing industry challenges and corresponding reduced newbuild rate, conversion projects have become commonplace and cruise lines readily acknowledge their importance. The president and CEO of Carnival Cruise Lines states that “the focus has to be on what you do with the ships you have” since “most of our guests will be going on the 23 ships we have now and not the new one coming in” [67]. Similarly, the CEO of MSC Cruises USA emphasizes that “lines must keep their ships up to date in order to stay competitive” and therefore “refitting and refurbishing is the key to the long and successful life of today’s cruise vessels” [3]. This outlook, along with the decreased rate of newbuilding, indicates that conversions will remain at the forefront of the industry in the future.

2.5 Summary

The modern cruise industry has a short history spanning less than half a century. Over this span, it has demonstrated relentless growth and is now the fastest-growing segment in the leisure travel market. In order to continue at such a successful rate, however, many challenges must be overcome. These include the global economic crisis that began in 2008, recent accidents, and fuel and environmental legislation. Additionally, the industry has entered a maturation phase due to its rapid globalization and ownership contraction, indicating that previous growth rates may no longer be attainable. Even so, future success in the global and U.S. contemporary markets is predicted and the industry has a strong record of resilience.

In order to remain competitive and offset a recent lag in shipbuilding, cruise lines are investing heavily in cruise ship conversions. Modern projects are more extensive, costly, and common than their predecessors. Potential savings and economic challenges indicate that such conversions will remain commonplace in the future.

3 Identifying current conversion drivers

Major characteristics of recent conversions are presented in the next two chapters. The intention is to study current conversion trends at both a broad, industry level as well as a narrowed, ship level in order to identify the need, purpose, and methods of today's conversion tasks. Conversion drivers are first specified with regard to the broader scope and are defined as the reasons used to justify such extensive and complex projects. Here, they are divided into two categories. The first is composed of drivers stemming from technical needs or considerations. The tasks undertaken due to company desires rather than obligations can be considered as strategic. Both types are discussed in the forthcoming sections.

3.1 Technical drivers

The reasoning behind many conversion tasks is technical in nature. A ship's age, for instance, directly affects conversion plans since upgrades are necessary in order to keep older vessels operable. Governing regulations, safety concerns, and operational efficiency also represent factors that cruise lines are required to consider when planning a conversion.

3.1.1 Vessel age

A vessel's age may have the most direct effect on conversion decisions, as maintenance costs increase along a ship's lifecycle. Correspondingly, the work required during a scheduled drydock is expected to increase as well. This is evident, as the previously mentioned rise in conversions is directly correlated to the average fleet age of today's major lines. With a decreased newbuild rate, these companies are operating older vessels in order to meet capacity demands. As shown in Figure 3.1, this has resulted in a pronounced increase in average fleet age over the past decade.

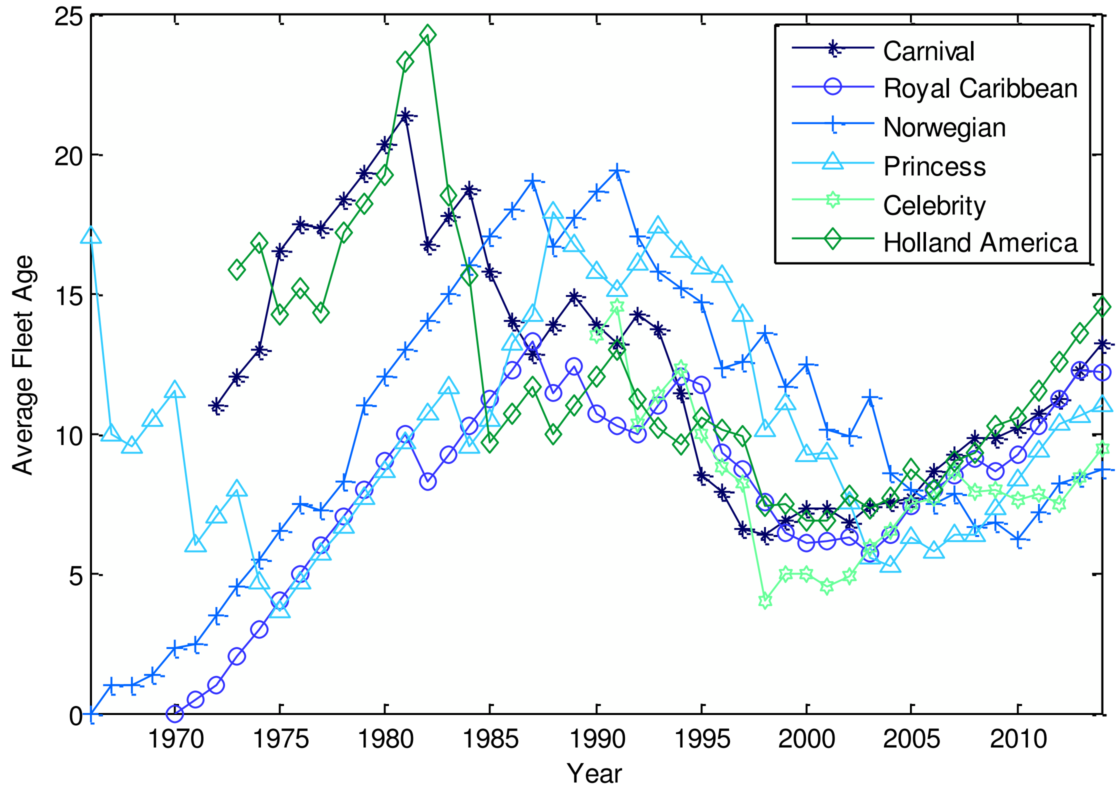

Figure 3.1. Average fleet age over time, major U.S. lines

Source: adapted from Appendix A

Figure 3.1 shows that ageing fleets are an industry-wide trend. Each of the six major U.S. lines has resorted to operating uncharacteristically old vessels, choosing to extend brand lives through refurbishments instead of selling or rebranding them. Table 3.1 shows this contrast by comparing the age of each company's oldest vessel with the average brand lives of retired vessels built by each line after 1980.

Table 3.1. Brand life statistics, major U.S. lines

Source: adapted from Appendix A

Cruise line	Oldest ship (2015)	Age (2015)	Previously operated ships	Average brand life
Carnival	Carnival Fantasy	25	Tropicale, Holiday, Jubilee, Celebration	21
Royal Caribbean	Majesty of the Seas	23	Song of America, Sovereign of the Seas, Nordic Empress, Monarch of the Seas	19
Princess	Sun Princess	20	Royal Princess, Star Princess, Crown Princess, Regal Princess	14
Norwegian	Norwegian Spirit	17	Norwegian Sea, Norwegian Dream, Norwegian Wind	16
Celebrity	Celebrity Millennium	15	Horizon, Zenith, Galaxy, Mercury, Century	15
Holland America	Prinsendam	27	Nieuw Amsterdam, Noordam, Westerdam	18

Each line is operating vessels above previous brand life figures and this trend is not limited to the oldest vessels. As depicted in Figure 3.1, fleets are ageing as a whole and each line is operating multiple vessels of considerable age. This is also illustrated in Figure 3.2, which plots both the total amount of ships operated and those over age 15 in terms of gross tonnage. Notable characteristics of the figure include the steep incline of total GRT in the early 2000's, the much more gradual incline in recent years, and the very steep incline of older vessels in recent years. These correspond to the surge in newbuilds at the beginning of the last decade, the current lag in newbuilds, and the trend of extending brand lives, respectively.

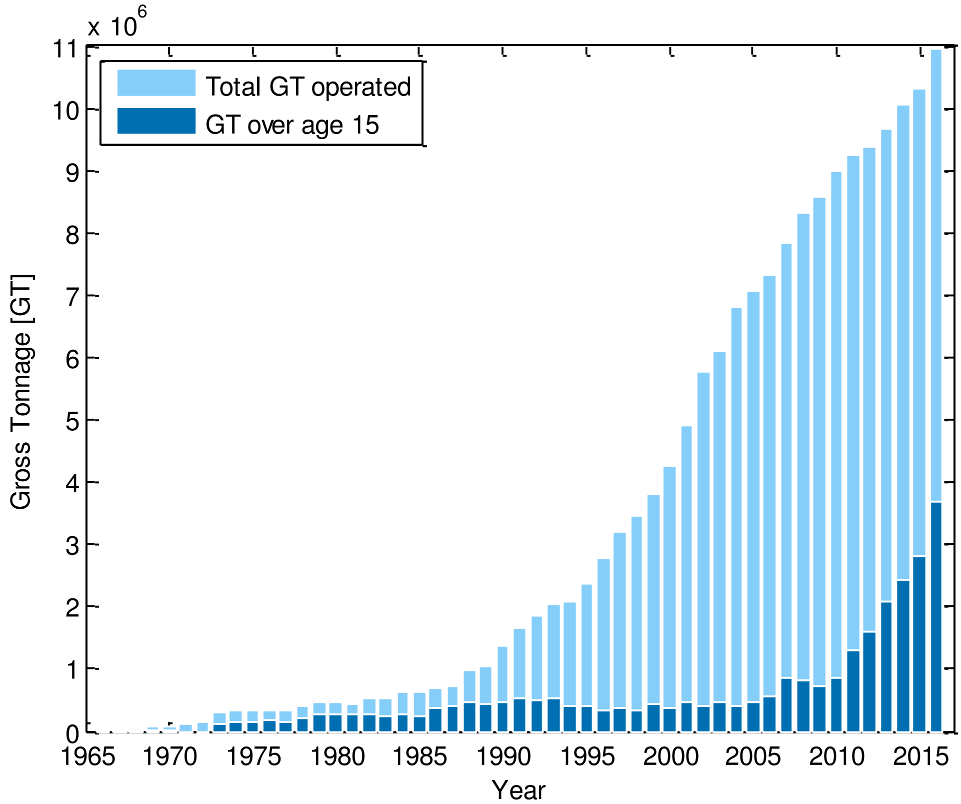

Figure 3.2. Fleet characteristics, major U.S. lines

Source: adapted from Appendix A

The trend of operating more vessels over age 15 is better visualized in Figure 3.3, which shows the same information as a percentage of gross tonnage. Here, the increased presence of older vessels is more noticeable. This percentage has been rising over recent years and the percentage of operated gross tonnage over age 15 is at the highest level in 25 years.

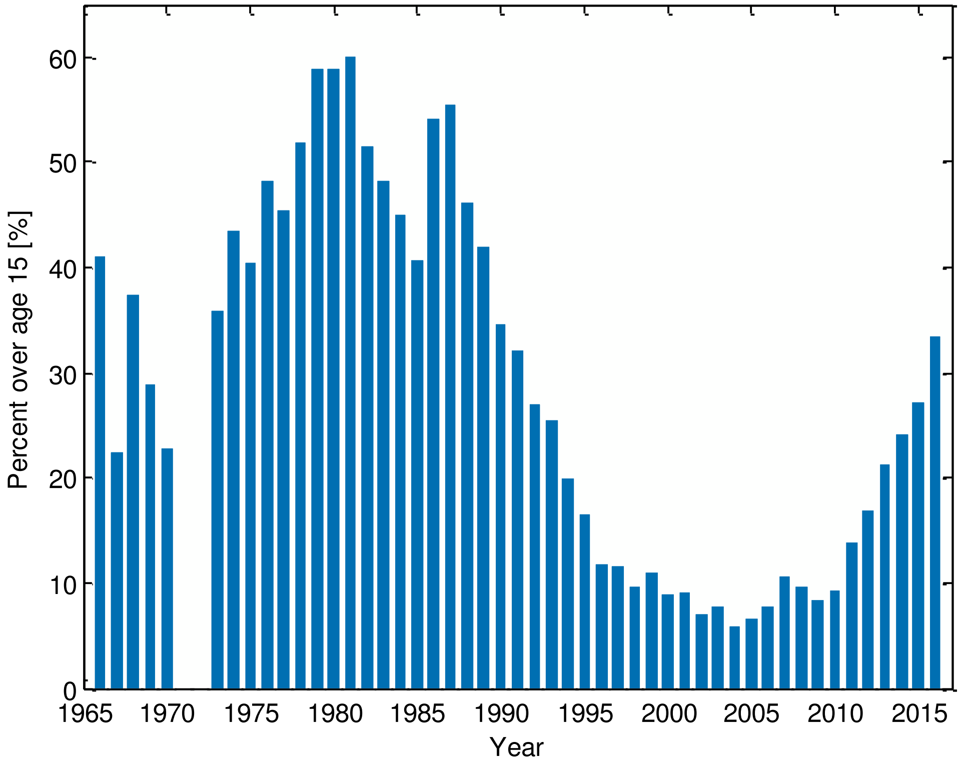

Figure 3.3. Percentage of fleets over age 15, major U.S. lines

Source: adapted from Appendix A

Such ageing fleets necessitate an increase in revitalization efforts and the trend of operating vessels beyond normal brand lives provides an unprecedented justification for conversions. Older cruise ships are difficult to maintain when compared to some types of vessels, as they are subject to a live payload in the form of passengers, along with stricter regulations and expectations. As such, degradation resulting from daily activities like food preparation and traffic must constantly be addressed before, during, and after each voyage [2]. Eventually, however, major updates are required to address more severe or recurring issues and inherent risks of machinery or equipment failure increase over time. A vessel's age is therefore a significant driver in planning a conversion. This driver is largely responsible for the renewed emphasis on ship revitalizations in order to operate ageing fleets in optimal conditions [1].

3.1.2 Rules and regulations

Applicable rules and regulations must always be followed in the planning, design, and execution of conversions. In this way, a conversion project is similar to a newbuild, where regulations are followed in order to ensure compliance. Some regulations, however, mandate modifications to existing vessels and thus directly influence conversion plans. In such cases, retroactive rules and regulations become crucial drivers.

A ship's design must comply with a number of regulatory bodies. For cruise ships, the most demanding include SOLAS and MARPOL, in addition to classification societies and more concentrated regulations such as PVAG and USCG requirements, among many others. Of these, the previously discussed amendments to MARPOL are the most influential with regard to conversions. In order to ensure both environmental compliance and economic feasibility, operators have invested in significant vessel modifications because of these changes.

Currently, the most popular solutions to reduce emissions at a minimal cost focus on fuel and abatement technologies, with an emphasis on adding exhaust gas scrubbers during conversions [25]. As mentioned, such equipment complies with recent amendments through equivalencies, where emissions are reduced to the same level as stipulated in MARPOL [49]. This allows operators to burn cheaper fuel with higher sulfur levels. Though advantageous from a cost perspective, long-term effects of scrubbing technology are unknown and they do have drawbacks. When considering conversions, one significant issue is the space available for installation aboard many ships, as well as the complexity of the retrofit itself. Scrubbers require large amounts of energy and their size and significant weight can potentially penalize a ship's payload [25]. With limited time to prepare for the changes, however, cruise lines have begun utilizing what is at present the most feasible solution.

With imminent compliance deadlines, conversion plans for many ships have been altered in order to allow for scrubber installations. Though the practice is still new, Carnival Corporation has allocated approximately $400 million USD for the retrofit of 70 of their vessels across many brands [68] and others are following suit. As more time and resources are utilized on the technology, their effects on conversion projects will diminish; developments towards smaller systems that may be fitted in lower spaces are already underway with the aim to improve weight, stability, and trim problems [69]. Still, due to their high investment cost and current retrofit challenges, some lines have decided against modifying existing ships, choosing instead to wait for further developments. In addition to more compact scrubber designs, the applicability of LNG, which has lower emissions than conventional marine diesel oil, is also being studied [49].

Emissions regulations currently have the largest impact on conversions, though numerous others are forcing modifications as well. In line with emission concerns are recent specifications on ballast water treatment. This is again a retroactive requirement that calls for ballast water treatment systems on all ships to avoid the spread of harmful organisms through filtration, ultra-violet lighting, additives, or a combination [70]. Together, these regulations have placed a greater demand on shipyards specializing in conversions [71]. Less stringent but nonetheless driving regulations are those related to accessibility, such as PVAG, which affects vessels calling at U.S. ports and carrying American passengers, and its European equivalents. Should a conversion introduce new cabin categories, for instance, a percentage would need to be designed for accessible passengers.

Though not exhaustive, the aforementioned and many other rules and regulations have directly driven conversion tasks in recent projects. This shows that they must be thoroughly considered during conversion engineering.

3.1.3 Operational redundancy

The primary purpose of regulatory bodies is to ensure the safe operation of subjected ships and safety is therefore a conversion driver by nature. Recently, however, cruise lines have utilized conversions to increase safety standards to levels above those stipulated. In this way, some safety considerations have become separate drivers in themselves. These drivers are coupled with operational concerns, as prominent modifications can potentially improve both safety and efficiency standards.

The aim to enhance safety above compliance levels is warranted due to the discussed accidents and their reputational and economic effects on the industry. To avoid similar events, one trend has been to improve redundancy by adding emergency generators or additional diesel generators. In the case of *Carnival Triumph*, negative publicity centered on the lack of redundancy in hotel service machinery. In response, Carnival Corporation initiated a $700 million USD program solely aimed at improving the safety and reliability of all vessels under its various brands. The main objectives of the program are to increase redundancy through the installation of additional diesel generators for key comfort loads and improve fire prevention, detection, and suppression systems. Additionally, engine room redundancies should be reviewed and improved to minimize the risk of propulsion losses [72]. Though Carnival Corporation experienced the largest reputational drawbacks, the industry was affected as an entity and other lines are increasing safety standards as well.

3.1.4 Weight and stability

A cruise ship's age is a direct conversion driver by necessitating maintenance and refurbishment work. Secondary effects include diminished stability characteristics due to weight gained over time, assuming proper lightweight growth and draft margins were not included at the design stage. This can be especially problematic for cruise ships, which gain much weight due to refurbishments, painting, and general buildup, along with other additions. Figure 3.4 shows the severity of the issue, with sample cruise ships demonstrating an average ten-year weight gain of over 3%.

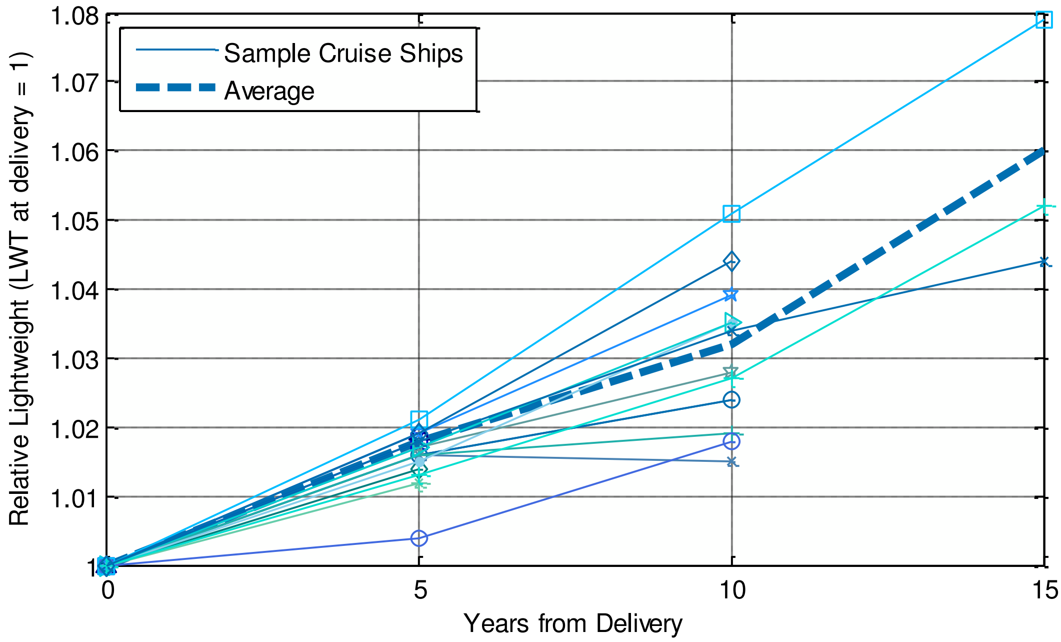

Figure 3.4. Lightweight development statistics

Source: based on [73]

Weight issues can proliferate for ships that have been converted. Conversion installations are often heavy and meant for higher decks, where added volume can easily be incorporated into the existing design. Equipment and entirely new structures like balconies, scrubbers, and partial decks can influence a vessel's stability. To compensate, significant modifications to the hull form may be needed. In the past, sponsons, which are permanent extensions to a ship's sides, were one solution. Their main purpose is to increase hull dimensions and thus the waterplane of a ship and, while effective in improving stability, a substantial disadvantage is the increased resistance that is typically experienced as a result [70].

Today’s conversions largely bypass this issue by installing an extension to a ship’s stern, known as a sponson-ducktail, rather than solely its side. Sponson-ducktails have similar effects in that they provide more displacement and a larger waterplane area to ensure sufficient stability for the after-conversion hull form [74]. The ship’s beam is not increased, however, and negative resistance effects are avoided.

The most direct advantage of the added appendage comes from the raised metacentric height (GM) which in itself is due to the increased distance between the keel and metacenter (KM). GM is crucial since it is the intact stability indicator. For a stable condition, GM must be positive, as this will result in a righting arm moment (GZ) that returns the ship to its initial, upright position. The GM increase does not explicitly guarantee an improvement in stability characteristics since added appendages affect stability limit curves, however. Even so, as a principle, improvements can be expected if the sponson-ducktail is of a proper design. The installation of a typical sponson-ducktail is shown in Figure 3.5.

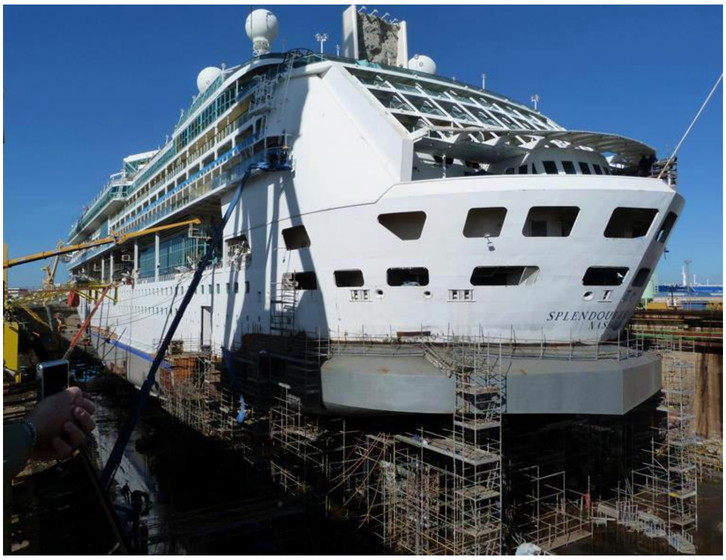

Figure 3.5. Sponson-ducktail installation, *Splendour of the Seas*
Source: [75]

Sponson-ducktail installations have become a common practice in today’s conversions to combat both general weight gains and heavy topside additions. The sponson-ducktail in Figure 3.5, for example, was designed to offset weight additions from conversion additions, such as new balconies, and ageing. To reduce negative stability effects due to concentrated loads, general weight increases, and conversion weight, sponson-ducktails have proven to be an effective solution. As with sponsons before, they should prove useful in the future as conversions become more complex and vessels are operated over longer brand lives.

3.1.5 Operational efficiency

A final technical conversion driver is operational efficiency. In this regard, technological advances and increased operating costs have spurred numerous conversion trends. With the need to minimize spending, cruise lines have been especially eager to maximize the operational efficiency of their ships and conversions have been advantageous in that regard.

There are many methods to improve the efficiency of a ship. Simple operational improvements can result in significant savings over time, especially when utilized congruently. These include optimized itineraries, reduced speeds, maintenance, energy efficient lighting and control, HVAC improvements, waste heat utilization, and frequency-controlled pumps, among others. For even larger savings, however, more permanent alterations and conversions are needed and the ship hull form and its appendages are the best energy saving possibilities in terms of propulsion power [76]. While more effective in reducing energy consumption, such changes are inherently more complex and often require significant conversion work.

Along with degraded stability, sponson-ducktails have the potential to improve efficiency. This is another reason for their popularity and another advantage over other types of appendages. In modern newbuild designs, ducktails are commonly incorporated into the initial hull form, though they are less pronounced in comparison. This stern shape is advantageous because it increases the aft body length without drastically changing a ship's overall length. This increase reduces the height of the transom wave pattern, improves the trim of the vessel, and results in a direct power reduction [76]. Where stability concerns have popularized sponson-ducktails in conversions, consumption and speed considerations have influenced newbuilds.

Sponson-ducktails can also potentially improve operational efficiency for converted ships, though by much smaller levels and generally for high speeds. Today, they have proven most useful for ships whose design was not optimal to begin with or no longer optimal with regard to new operational profiles [77]. The common convention in cruise ship design has been to optimize hull forms for a specified design draft and speed. With the potential consumption savings of sailing at lower speeds, however, projects have been contracted to optimize existing hull forms for off-design conditions [74]. Such projects investigate not only the design speed, but also various lower speeds and drafts covering a wider range.

Conversion results are promising, as more slender sterns made possible with sponson-ducktails can reduce the wave resistance in a similar fashion to newbuild designs. This occurs due to reduced transom waves and aft shoulder crest waves when compared to traditional hull forms [78]. This improved wave pattern results in a better pressure distribution in the aft end of a vessel, which in turn improves performance [79]. Various studies have been presented with positive results, though these, unlike those regarding stability, have many caveats. Significant improvements are generally attainable only at topmost speeds, which are seldom, if ever, used in operation. Usually, sponson-ducktails actually have a small negative effect on a vessel's speed-power curve at lower speeds due to the increased displacement, which is reversed at higher speeds because of an increased waterline length. Stability improvements necessitate their inclusion, however, and this overrides the slight declination in the speed-power relationship at operational speed profiles.

Another potential improvement is the addition of an interceptor plate, or simply interceptor, to the transom. This is a metal plate that pushes the flow of water downwards to create a lift effect on a vessel's aft-body [77]. The created lift effect can further reduce propulsion power demand and can potentially compensate for reduced post-conversion speeds. While again more beneficial for higher speed vessels like ferries, they have already been installed on cruise ships with positive results and have been estimated to reduce power demand by up to 6% on their own [78]. Negative effects are also possible, however, and other tests have demonstrated negligible improvements stemming from their inclusion.

Additional advantages of interceptor plates are their simple installation during retrofit and compatibility with a sponson-ducktail, though their combined potential is less than the sum of their separate ones. Resulting energy savings vary according to a vessel's original design, though the ease of retrofit and cost-effectiveness make both technologies feasible and both have been successfully retrofitted to existing vessels. Again, however, measurable results are common only at high speeds.

A third hull form characteristic that can be altered during a conversion is the bulbous bow. Bulbs have been replaced in conversions for various ship types, although there has been little focus on cruise ships. As with cruise ship sterns, older bulbs were optimized for the original design draft and speed and not for a ship's complete operational profile or current design draft [78]. This is in contrast to modern bulbs, which are designed for a range of drafts and cruising speeds. The result is a different shape in terms of contour, waterline shape, and profile that contributes to respective reductions of 5% and 10% or more for resistance and propulsion power at the optimized speeds [79].This represents an opposite tradeoff from before, as new designs yield losses at higher speeds. The drawback for bulb conversions is their complexity, as they are expensive to manufacture and would result in lengthy payback periods.

Each of these hull form changes shows potential in improving the operational efficiency of older cruise ships. Sponson-ducktails and bulbous bows have particularly high initial costs and require longer conversion periods, though they are viable options due to potential savings over long periods. Their payback periods hinder their inclusion, however, and simpler conversion tasks such as the addition of thruster grids and scallops are more probable. Such changes require little planning or construction work and still can improve efficiency.

3.2 Strategic drivers

Whereas a vessel's age and governing regulations can be viewed as obligatory drivers, many changes made during conversions are made at the discretion of the operator. Recently, even newer ships have undergone conversions in order to ensure their relevance in comparison to recent newbuilds. Many spaces are also reconfigured to maximize onboard revenue or guest experience and such conversion tasks are not influenced by technical factors. These drivers are thus viewed as strategic, since they stem from company aims rather than technical reasoning. While conversion additions spurred from technical drivers are generally crucial to a ship's operation, those added for strategic reasons are often in the form of amenities.

3.2.1 Revenue

The direct costs of drydocking a cruise ship are high, though the cost of steaming to the yard along with the resultant off-hire period result in the largest revenue losses [2]. It is therefore important for cruise lines to generate increased income in order to minimize the payback period and maximize future profits. On a small scale, simple changes can easily increase profits, especially through onboard revenue. Studies show that an increase in onboard attractiveness leads to higher onboard spending and more net onboard revenue [56], meaning quick refurbishment tasks such as replacing carpeting or furniture can possibly yield measurable results. Effective marketing strategies can also increase demand for a given ship and therefore booking volumes. New cruise ships generate their own market for at least 12 to 18 months and a rejuvenated older vessel can often have the same impact [41]. Though increased sales are not as long lasting as those for newbuilds are, conversions can nonetheless be used to mitigate the effects of fewer new ships.

Even with the advantages of small refurbishments, cruise lines have used larger conversions to enhance profits further. Specifically, adding passenger cabins and introducing new surcharge venues are popular for the major cruise lines. Increasing the amount and variety of surcharge venues, especially restaurants and exclusive sun decks, both bolsters profits and meets passenger demands. This is a significant change from the traditional cruising experience. Before, most ships featured only one specialty restaurant, if any. Now, however, tourists prefer choice and variety, even if they come at a price, and passengers now expect extra-fee products and services [13]. The result has been a surge in such venues, with new ships featuring a large variety of dining options and older ships being retrofitted similarly.

The trend of adding cabins to existing and new spaces is also growing [1], [31]. By increasing the number of cabins, cruise lines are able to increase profits through ticket sales and onboard revenue. Contemporary conversion examples include fitting cabins into previous public spaces such as lounges, atriums, and dining rooms, as well as former crew spaces. More extreme examples include the addition of new deck areas and midship sections, which allow for a larger increase in balcony cabins. These trends illustrate the driving importance of revenue on all major decisions.

3.2.2 Fleet standardization

As new ships become larger and more advanced, cruise lines are forced to modernize older ships in order to maintain a standardized fleet. This is crucial for the major brands, as it is important that their older, more traditional ships do not become obsolete in comparison. While major competition comes from rival companies, cruisers must also make decisions at the sub-brand level by choosing a vessel. The decision is most often based on the itinerary or ship, where newer ships are generally preferred [80]. Though age is a factor, cruise lines can minimize differences in onboard offerings by retrofitting older vessels with concepts and venues introduced on newer ones.

It is important for operators to provide a predictable experience across all ships. Predictability is one of the important aspects of the industry, as a consistent customer experience becomes synonymous with a cruise brand and drives loyalty as a result [81]. If brand congruence is not emphasized, cruise lines may face similar problems being encountered by hotel chains, where it is no longer possible to predict the quality of accommodation by the name of the brand [5].

To facilitate product uniformity, cruise lines often build ships from nearly identical sets of architectural plans, which also enables larger economies of scale in terms of operational and building costs [13]. Still, in order to maintain uniformity across different ship classes, major lines have invested heavily in conversions. For Royal Caribbean, modernizing older ships has been a priority for many years, beginning with the installation of rock climbing walls on its ships after the first was introduced on *Voyager of the Seas* in 1999 [82].

More recently, the company has invested in its Royal Advantage program, where three to five ships per year have been scheduled for conversions with the aim of adding features found aboard their *Oasis*-class vessels. In 2012 alone, the line spent $131 million USD on the conversion of three ships in order to introduce new onboard amenities, staterooms, and restaurants [31]. The intention is to upgrade the entire fleet by 2016. Ambitious programs have also been adopted by Celebrity Cruises, Disney Cruise Line, and Carnival Cruise Line to bring existing vessels up to par with their newest *Celebrity Solstice, Disney Dream,* and *Carnival Dream* classes, respectively [3], [83]. Though some enhancements are difficult to introduce, cruise lines have realized that many more new features can be retrofitted to older vessels than once expected [84], resulting in a high level of brand congruence.

3.2.3 Deployment

A third strategic driver is a vessel's intended area of operation or market segment. Though the scope of this thesis concentrates on the contemporary U.S. market, many conversions are designed to meet the needs of new customer bases. This intention has been commonplace throughout the industry's history and is often carried out when a line enters a market for the first time. Cruising expectations are extremely dependent on ethnicity [8], which, along with the destinations visited, serves as one of the key motivational differences among cruisers [80]. It is therefore important that a ship meet the needs of its intended passengers.

Cruise lines have long acknowledged passenger differences and addressed them through conversions. Before deploying a modern ship to the U.S., for instance, Costa Crociere invested in a major conversion that considered the differences between European and North American cruisers, including cuisine, service, and lifestyle preferences. As a result, the deployed ship emerged with a higher emphasis on entertainment and onboard passenger spending [4]. The major U.S. lines have initiated similar projects when expanding into new markets. Royal Caribbean introduced new gambling and retail spaces aboard its China-based ships [85] and Princess Cruises converted existing spaces to a Japanese bath area and added new dining venues before deploying their latest ship to the region [86]. Other conversions have been aimed at Australian, Brazilian, and German cruisers, among many others. Even new ships are subject to redesign. One recent example is Royal Caribbean's newest vessel, *Quantum of the Seas*, which underwent late, large general arrangement changes following the decision to deploy her to China [87]. History thus shows that a vessel's deployment has a large impact on conversion plans and the same is true for a vessel entering a different market segment. Before a contemporary ship could successfully re-launch to the luxury market, for example, many changes to public spaces and cabins would be mandated, since luxury ships should feature higher crew and space ratios per passenger [12], among other differences including outfitting details.

3.2.4 Market competitiveness

The cruise industry's competitive nature can significantly drive an operator's agenda in various ways. Popular amenities from competitor ships, for instance, can inspire conversion tasks similarly to new ships within a brand. Though cruise lines aim to standardize their own vessels and differentiate them from competitors, many once-novel ship features have become commonplace across brands. Outdoor movie screens, water slides, rock-climbing walls, and mini golf courses represent amenities that were once confined to a single brand but have since become industry standards [3], [84]. These features and more have been included in both newbuild and conversion designs and this trend will continue as new ideas are developed.

The lack of a robust secondary market also indirectly affects conversions by prolonging brand lives. By selling a vessel, an operator not only reduces their carrying capacity, but also potentially provides a rival operator with a vessel that could be deployed in direct competition with a former fleet-mate. To avoid this scenario, operators may choose to maintain or convert a vessel for continued service or re-brand it by transferring it to a sister company. One common practice is to continue operation until no longer feasible before transferring a ship to a sister cruise line that caters to a less demanding market [88]–[90]. In rarer cases, lines have redeployed a previously transferred ship to its original line rather than sell it to a competitor

[91], [92]. This awareness influences conversions through both brand life extension and re-brandings that may feature significant conversions aimed at new target demands.

3.3 Summary

Conversion drivers are the reasons used to justify today's expensive, time-consuming, and complex conversion projects. Generally, they fall into one of two categories. The drivers that are technical in nature are mandatory drivers whereas strategic drivers are implemented at the discretion of the operator.

Each of the technical drivers is directly related to the current industry challenges highlighted in Chapter 2. They include a vessel's age, governing regulations, operational redundancy, stability, and operational efficiency. Examples of conversion additions spurred by these drivers are exhaust gas scrubbers, emergency generators, and sponson-ducktails. Strategic drivers include revenue concerns, fleet standardization, deployment, and competition. Passenger cabins and amenities are commonly added during conversions for strategic reasons.

4 Identifying common conversion cases

While the previous chapter presented conversion trends at the industry level, this chapter focuses on a narrow vessel scope. The first aim is to identify prevalent conversion tasks of today's projects by studying recently converted cruise ships. These tasks are then used to compile a list of probable cases that serve as the foundation for later recommendations.

4.1 Today's conversion tasks

A conversion task is an action completed during a conversion project. In order to develop initial design recommendations, it is important to first identify which conversion tasks are probable farther along a vessel's lifespan. Three reference cruise ships are studied in order to demonstrate what actions are commonplace in today's projects.

The three ships, *Brilliance of the Seas*, *Disney Magic*, and *Carnival Sunshine*, are chosen for their contrasting characteristics. As vessels, each shares enough similarities to yield generalized results. This is true with regard to the age, size, operation, and conversion date of each. All three ships sail for a contemporary U.S. cruise line and currently serve the Caribbean market from Florida. In terms of specifications, each was designed to carry over 2,400 passengers, was launched between 1996 and 2002, and was converted in 2013.

Equally important, however, are the few crucial differences between the vessels. Findings should be applicable across the entire contemporary U.S. market and not confined to a single brand; fleet mates are therefore not considered. This approach also highlights the priorities of the three cruise lines being considered. The intensity of the conversions also differs in order to illustrate the broad scope of such projects.

Before and after specifications and deck plans are used to identify the significant conversion tasks for each ship. Since such deck plans are generally available only for public decks, crew and service spaces are not a major focus. Additionally, there is less focus on minor conversion tasks. In contrast to the tasks requiring structural modifications, smaller ones such as space refurbishments have a much lower impact on the project, are more difficult to predict in advance, and therefore have fewer implications on a vessel's initial design. Conversion tasks for each ship are summarized in the forthcoming subsections. Complete lists of identified tasks, along with relevant information including specific descriptions, are provided in Appendix B.

4.1.1 Reference ship A – *Brilliance of the Seas*

The first of the three reference ships is the youngest and its completed conversion the least extensive. An approximate $30 million USD conversion was completed for *Brilliance of the Seas* in 2013 as part of Royal Caribbean International's Royal Advantage revitalization program. The majority of the conversion tasks aimed to add features found aboard the line's newest *Oasis*-class vessels, including new onboard amenities, stateroom upgrades, and restaurants [31]. As such, the desire for a standardized fleet served as the main conversion driver for the project.

A comparison between arrangement plans reveals specific conversion goals that were realized through each task. The first of these is the division of former spaces in order to introduce venues found aboard newer ships. The previous Viking Crown Lounge, for instance, was divided into three separate spaces: the Diamond Club, Concierge Club, and a smaller version of the same lounge. A similar conversion divided an open dining area on deck 11 into two separate dining areas, one for the existing buffet and a second for a new restaurant.

In an opposite case, some small spaces were combined into a larger space by removing bulkheads. This is the case for the former Country Club and adjacent golf simulator room, which were combined to form a single arcade, for instance. A third apparent goal is the addition of new cabins, which most commonly replaced public spaces. Atrium spaces were especially prone to conversion, as four former atrium lounges were replaced with passenger cabins over three decks. Cabins were also added to a former dining and service space for a total increase of 18 staterooms. An example of a typical atrium conversion is shown in Figure 4.1, where two of the aforementioned lounges are converted into a passenger cabin and suite.

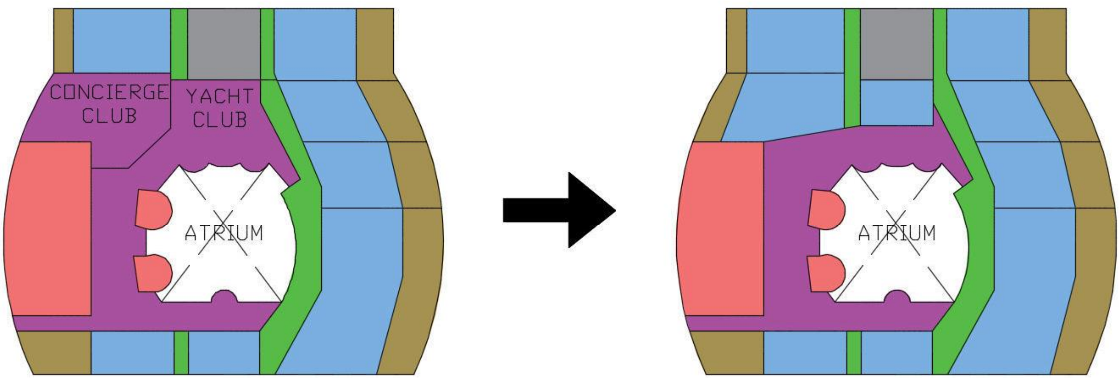

Figure 4.1. Atrium conversion, *Brilliance of the Seas*

The enlargement, division, and repurposing of spaces represent significant arrangement changes. In addition to these, various other tasks were completed with smaller impact on the vessel's arrangement. These include the addition of entertainment amenities such as a new on-deck movie screen and a winch system above the atrium. Finally, many existing spaces were refurbished without significant structural alterations. Examples of these smaller tasks include the refurbishment of former restaurants, bars, and lounges into new, yet similar spaces. Table A 12 shows all identified tasks completed during drydock.

4.1.2 Reference ship B – *Disney Magic*

Disney Magic represents the intermediate reference ship in terms of both age and intensity of completed conversion work. In addition to the vessel's age, many of the conversion tasks were again driven by fleet standardization aims. These two conversion drivers were emphasized by the operating cruise line, as there was a specific plan to reinvest heavily once the vessel entered the latter stages of its lifespan and introduce features found aboard their newer *Disney Dream*-class vessels [83].

Unlike *Brilliance of the Seas*, the *Magic* emerged from the conversion with significant external modifications. The most apparent is the addition of a sponson-ducktail as compensation for the vessel's weight gain over time and concentrated conversion weights added during the drydock. Figure 4.2 shows the sponson-ducktail added during conversion.

Figure 4.2. Sponson-ducktail, *Disney Magic*
Source: [93]

Additional external changes can be seen on various aft open decks, which were rebuilt both for public and service purposes. The existing buffet restaurant was extended onto the adjacent aft deck while open deck space on deck 7 was converted into a new emergency diesel generator room. Similarly, the beauty salon on deck 9 was extended and new stores and salon spaces built on an adjacent deck area. A schematic of the buffet and galley extension is shown in Figure 4.3 and is also evident in Figure 4.2.

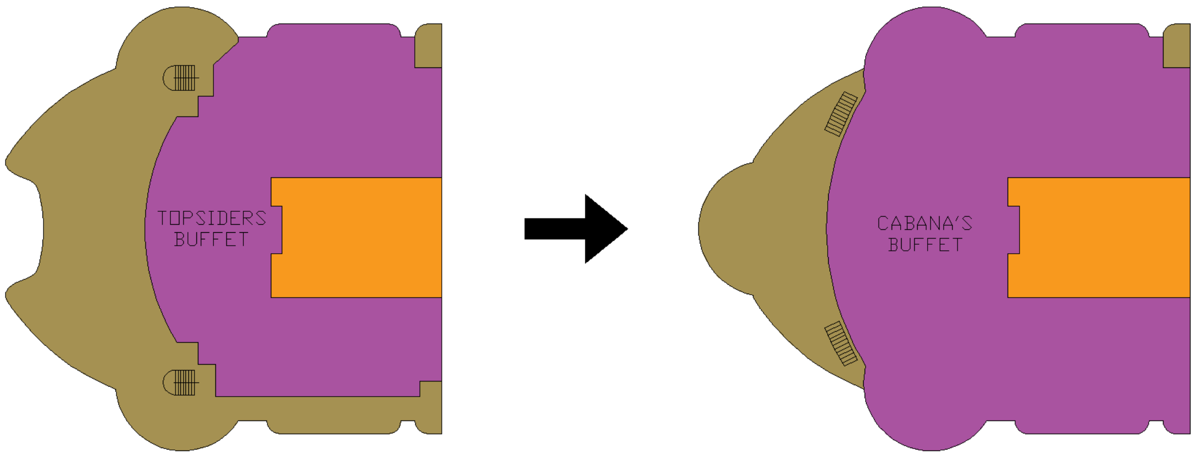

Figure 4.3. Restaurant conversion, *Disney Magic*

New amenities were introduced on the upper decks in the form of one new and one replaced waterslide. Aside from the extensive outer deck conversions, interior alterations included the division of children's facilities into smaller spaces, the expansion of smaller nursery areas into a single space, and general refurbishments to restaurants, shops, and the atrium. A full list of modification tasks is given in Table A 13.

4.1.3 Reference ship C – *Carnival Sunshine*

Carnival Sunshine is the oldest and largest of the three reference ships. It is also the vessel that saw the largest conversion work completed, with Carnival Cruise Line determining that the work was extensive enough to mandate a relaunch, complete with a rename from *Carnival Destiny*. When launched, the *Destiny* was the largest cruise ship in the world and was so popular that bookings of up to a year in advance were needed [28]. After 18 years, however, she was comparatively outdated and in need of major maintenance work.

As with *Disney Magic*, both age and standardization issues drove the majority of the plans. According to Carnival Cruise Line, the two main conversion factors were the vessel's need for a significant makeover and the popularity of features that had already been introduced on other vessels [3]. The result was a $155 million USD conversion that added these features along with other major structural changes, including the addition of 182 new cabins [31].

When compared to the previous reference ships, the before and after arrangements of the *Sunshine* show that its operator, Carnival Cruise Line, had a much higher desire to add as many passenger cabins as possible into both existing and new spaces. Whereas added cabins aboard *Brilliance of the Seas* represent a double occupancy increase of only 36 persons, those on *Carnival Sunshine* correspond to an increase of 364 passengers based on double occupancy. In comparison to the figures specified for *Carnival Destiny*, this represents a 14% lower berth increase. While some new partial decks were added to facilitate a portion of these cabins, the space increase as a measure of gross tons is not proportionate to that of passengers.

Of the 182 cabins added during the conversion process, less than half were allocated to the new partial deck structures or open deck spaces while the remainder replaced existing public spaces. Such space was converted from former spa, sauna, lounge, and theater areas. The latter were especially large in scope, as the Criterion Lounge area and lower level of the main theater were converted into 50 and 41 new cabins, respectively. The lounge conversion is shown as an example in Figure 4.4.

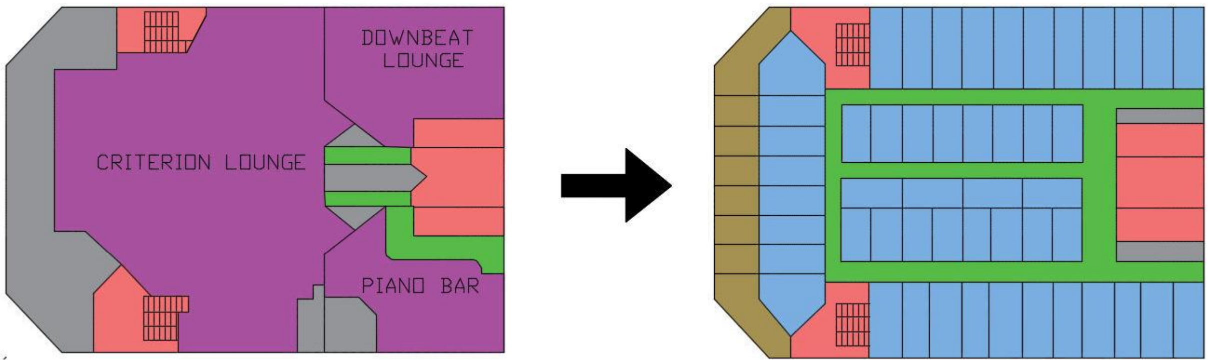

Figure 4.4. Lounge conversion, *Carnival Sunshine*

Along with the addition of new partial decks onto the forward superstructure of the ship, other open deck conversions included the rebuilding of the aft pool deck into a buffet extension and the addition of water slides and sports equipment on the deck above. Interior conversion work was also extensive. This included the division of large spaces such as the dining room, casino, and large dance club into multiple spaces including smaller dining rooms, children's facilities, and an arcade, among others. A complete list of conversion tasks is provided in Table A 14.

Of note is that, even with the large volumetric and cabin additions, a sponson-ducktail was not included in the conversion design.

4.2 Probable conversion cases

In order to identify preventive measures that can be implemented during the initial design process, probable future conversion scenarios must first be specified. These conversion cases should represent a balance between generality and detail. In one regard, they should cover the majority of potential conversions so that the precautionary measures later identified will ameliorate as many conversion processes as possible. Too much detail, however, should be avoided. Specifying a large number of very specific conversion cases would yield fewer helpful implications due to the impossibility of predicting exactly what will be done in a future conversion. Though it is highly probable that a given newbuild will experience a major conversion during its lifecycle, predicting precise tasks are impossible due to the industry's fast pace. While the tasks identified through the three reference vessels are indicative of current trends, their applicability may decrease as passenger and market profiles evolve.

By considering these tradeoffs, four probable conversion cases are identified. The first three are related to arrangement modifications regarding large public area, small public area and cabin, and outer deck conversions. The final case is the addition of concentrated conversion weights since this is an important factor in each reference case. When combined, the cases are broad enough to cover each identified reference task listed in the Appendix B tables. There, conversion cases one through four correspond to those covered in sections 4.2.1 through 4.2.4. This generalization of cases yields easier predictability in early design stages. For example, while it is impossible to predict exactly what a large public space will be converted into in the future, it can easily be acknowledged that a conversion aimed to divide the space is probable. Whether the space is divided into a cabin area or smaller public spaces is irrelevant as long as the provident measures identified are conservative enough to cover all prospective scenarios.

To categorize each case more effectively, spaces are specified in accordance to SOLAS fire integrity categories. Appendix C provides a list of each category along with a consolidated description of applicable areas, though dual category spaces are also common. With respect to the three reference ships, only some of the categories represent areas that are likely candidates for conversions. These are discussed in the following subsections and shipboard areas are identified interchangeably with their respective categories throughout the remainder of the thesis. In addition to the conversion case descriptions, sample schematics for each case are shown in Appendix D. These are taken from the reference ships as well as comparable vessels in order to illustrate the wide array of conversion possibilities.

4.2.1 Large public space conversion

The first case is the most common in today's conversion projects. It represents the scenario in which a large public space is divided into multiple, smaller spaces. The current trend is to divide a public area into a cabin area in order to increase a vessel's capacity and thus it's earning potential. Figure 4.1 and Figure 4.4 both show examples of this case, with similar cases provided in Appendix D.

A second possibility is to divide a large public space into smaller public spaces instead of cabins. This trend is featured on each of the reference vessels, with former lounges and children's facilities being divided into spaces that are more manageable. The direct revenue of this type of conversion may be lower than that for cabin areas, but it allows operators to introduce new venues into existing spaces. This can benefit a given ship in terms of fleet standardization and revenue, assuming some spaces are designated as surcharge venues.

Potential conversion areas for this case have fewer constraints than those that follow. Past projects have featured the conversion of large public spaces in many different areas of their respective ships. When being converted into a cabin area, however, such spaces are generally confined to forward and aft public spaces. This is due to the design of more centrally located spaces, which have dual purposes in both accommodating passengers and acting as a passageway to other areas. If a cabin area were fitted amidships on a public deck, for instance, large bisecting corridors would be needed to accommodate the number of passengers for which adjacent public spaces are designed. Dividing a large space into smaller public spaces is less constricted, assuming the new spaces are served by the same passageways.

In terms of space categories, this type of conversion generally features a category 8 space being divided into either category 7 cabins or small public spaces, or smaller category 8 spaces. Category 3 spaces are also a factor, especially in the cabin scenario, where various corridors are needed for evacuation since category 7 spaces cannot open directly into staircases. These three categories therefore represent the critical factors for this type of conversion, though others may be present if located within or adjacent to a large space in question. Category 13 pantries or category 9 restrooms, for instance, are commonly located in such a zone. Of note is that, according to SOLAS, atriums are defined as public spaces within a single main vertical zone that span three or more decks. While technically category 8 spaces, they have stricter requirements than smaller ones. Another consideration is that a former space is not always a category 8. Though much less common, some conversions have fitted cabins into former service spaces, including pantries and crew facilities.

4.2.2 Small public space or cabin area conversion

The second conversion case contrasts the first. Here, smaller spaces are merged into a single larger one. This case is not as common, though it has been featured in various projects and has large implications for future conversions. In past projects, this represents the ability to eliminate seldom-used or redundant spaces and gain a larger, more functional space as a result. Examples from the references and additional ships mainly comprise of small public areas being combined. Additional possibilities could be utilized in forthcoming projects, however, including the potential conversion of an existing cabin space into a public one. If a vessel were rebranded into a more luxurious market, for instance, an increased passenger-space ratio would be necessitated. Similar aims could be sought in terms of fleet standardization or competition.

Applicable areas for this type of conversion are narrower than in the first case. For convertible cabins, the most feasible areas are limited to decks on which both cabins and public spaces are present, which are generally the lower and upper-most cabin decks. While conversions on decks solely comprised of cabins would be possible, the logistics would be more challenging due to the physical differences between such spaces, including deck height. Public areas with the potential to be combined are less limited, as many category 7 or 3 public spaces can be merged with adjacent ones in order to create a larger room.

The critical categories for this case are identical to the first. Here, category 7 or 8 spaces, along with category 3 corridors and smaller space categories like category 9, are transformed into a single category 8 venue. Though less likely than the first case, this case will commonly yield greater challenges, since a category 8 space is subject to stricter regulations than a category 7. This relationship will be further explained in the following chapter.

4.2.3 Outer deck conversion

The final arrangement case has become increasingly popular over recent years. It represents a conversion in which an open deck space is rebuilt into an enclosed area. As with the first case, the resulting space can either be public or comprised of cabins. Again, the cabin area scenario is more popular today, though there are many examples of a deck being replaced with public spaces. One example of the latter case is shown in Figure 4.3, where an existing restaurant is enlarged through expansion onto the adjacent open deck. Even for smaller modifications, such as the addition or conversion of a macrodome space, fire integrity categories may change. Sample arrangements for both types of conversions are provided in Appendix D.

Given the superstructure shape of modern cruise ships, the only feasible areas for this type of conversion are on the uppermost decks and further confined to the fore and aft-most areas. While midship conversions are possible, these spaces are generally allocated to crucial passenger areas such as the main pool. Recently, adding structures to both fore and aft sections have been popularized, with as many as three partial decks added to former open deck spaces. Affected categories with the greatest impact vary depending on intention. If converting the space into a public area, category 5 and category 8 will be the focus. For a cabin area conversion, categories 7 and 3 will replace category 8 in importance.

4.2.4 Weight addition

Whereas the first three cases represent arrangement alterations, the final is related to the weight, stability, and profile of a cruise ship. As discussed in Chapter 3, varying conversion drivers have resulted in concentrated loads being added during a conversion drydock. For the reference conversions, additions include movie screens, deck structures, water slides, and a pool. Though not greatly influencing a ship's general arrangement, these additions affect overall characteristics including stability, as covered in Chapter 3.1.4. Additional weight can also be indirectly added with the conversion of public spaces to cabins. This is due to a cabin area's large weight per unit when compared to other spaces. For passenger ships, outfitting weight contributes to a large percentage of the total lightweight and the outfitting for cabins is very concentrated per area unit. Fitting cabins into existing spaces can therefore expound weight issues, especially for conversions already featuring volumetric additions. With such implications, it is important to consider this conversion case at the initial design stage in order to better prepare for the adverse effects at the onset of a vessel's lifespan.

4.3 Summary

Conversion tasks, or the actions completed during a drydock, are broad in intention and complexity. By focusing on three reference cruise ships, however, overarching trends become apparent. In order to present preventive measures that can be implemented at the early design stages, all identified conversion tasks are sorted into four distinct conversion cases. The first conversion case represents the scenario where a large public space is divided into smaller ones. This is typically utilized in order to increase the cabin count without adding new structure. The second case depicts the opposite, where smaller spaces, either private or public, are merged into a single larger space. The final arrangement case focuses on open decks that are converted into enclosed cabin or public areas. Finally, additions of concentrated conversion loads are included in order to identify solutions to reduce their stability effects.

5 Defining initial design implications

With the core conversion cases identified, this chapter covers their initial design impact. The major goal is to identify what design factors influence the completion of each case as a foundation for the specific recommendations proposed in the forthcoming chapter. This is completed by examining the challenges and solutions of each conversion case with regard to the common conversion tasks completed.

The initial design implications are studied with respect to three disciplines: structural fire protection, means of escape, and stability. These disciplines have very tangible impacts on conversions and are crucial factors in the beginning design stages. Additionally, the conversion tasks and cases discussed in the previous chapter are directly related to these considerations. The first three conversion cases represent arrangement modifications requiring structural changes and redesigned access and egress spaces. The addition of concentrated weights can be a stability issue, as discussed in Chapter 3.1.4.

The following subsections cover each discipline. Reasons for their inclusion are given before studying their impact on initial and conversion engineering. Where applicable, regulatory requirements are presented and methods for improvement and later final recommendations are based on these. As such, the thesis takes a rules-based approach to define the challenges, implications, and solutions for the conversion cases and disciplines.

5.1 Structural fire protection

Structural fire protection considerations are defined in SOLAS Chapter II-2, Construction – Fire protection, detection and fire extinction. More specifically, Part C – Suppression of fire, section 11 – Structural integrity, forms the basis of this section. The aims of fire protection regulations are to prevent the occurrence, severity, and impact of potential fires or explosions. The division of a ship is a key method in meeting these goals. Requirements for both the major division into main vertical and horizontal zones as well as the subdivision of accommodation spaces are stipulated in SOLAS. One consideration, however, is that many current SOLAS rules were introduced in the early 1990s, meaning earlier vessels followed different rule sets which must be considered in conversion engineering.

5.1.1 Regulatory stipulations

A cruise ship's division must meet strict requirements with regard to both quantity, in terms of the number and size of main fire zones, as well as quality, in terms of materials used. When dividing any given accommodation space from an adjacent one, minimum bulkhead and deck quality requirements must be followed. These requirements are given in the form of fire integrity tables, which are provided in Appendix E.

Based on which fire integrity categories are separated, bulkhead and deck insulation of either A, B, or C-integrity must be used. Integrity refers to the thermal level, with A being the most stringent and C the least. To be considered an A-division, the steel or equivalent material must be insulated with non-combustible materials so that, in the event of a fire, the unexposed side will not rise more than 140°C above the original temperature, nor will any point rise more than 180°C above the same. In addition, they must prevent the passage of smoke and flame for one hour in given fire tests. B-divisions must also be constructed of non-combustible materials. The total temperature increase can rise to 225°C above the original and the same fire test must only be passed for thirty minutes, however. Finally, C bulkheads and decks need not meet any of the aforementioned requirements except for the stipulation that they must be composed of non-combustible materials.

In addition to integrity, boundaries are further divided into categories. Represented by a number, each specifies the time for which the temperature rise limits must be adhered. For instance, an A-60 steel bulkhead must suppress the temperature to necessary levels for 60 minutes. A-60 thus represents the most suppressive, followed in order by A-30, A-15, A-0, B-15, B-0, and C-integrities.

The tables in SOLAS and Appendix E represent only minimum suppression requirements and more stringent insulation can be used at any time. The tables are also only valid for bulkheads and decks that do not act as a main vertical or horizontal zone boundary. For cruise ships, all main vertical zones must be of A-60 material unless category 5, 9, or 10 spaces are on one or both sides of the division. In the latter cases, A-0 is compliant.

Finally, while the main zone and subdivision requirements should be followed for all cruise ship designs, exceptions can be made. As defined in SOLAS Chapter II-2, Part F, Regulation 17, fire safety design and arrangements may deviate from the prescribed requirements as long as the proposed design is equally effective in meeting fire safety and functionality standards.

In order to be approved, engineering analysis and evaluation must be provided. This regulation has spurred various alternative designs in modern cruise ships, including main vertical zones that are excessively large according to traditional fire safety standards.

5.1.2 Impact on conversions

Structural fire protection is one of the most influential concerns in conversion planning. This is because, in accordance with SOLAS, all converted ships must continue to comply with at least the minimum previously applicable requirements. For new, large areas, such as partial decks or midsections, this means that the regulations must be followed in the same manner as for newbuilds. When converting an existing space, however, there are many more complications. Not only must the new dividing bulkheads be compliant, but so must existing decks and bulkheads. Therefore, if a former area is converted from one fire integrity class to another, it is probable that existing insulation must be replaced with higher-grades. This is both time consuming and expensive for the owner and shipyard, especially in projects where a vessel undergoes a major conversion over many accommodation areas. Such modifications also require significant downstream investments, as detailed plans must be produced. A vessel's structural fire protection plan, for instance, must be carefully checked and most likely updated significantly before being submitted to governing authorities for approval. This is a time-sensitive issue since approval must be granted before a conversion begins.

5.2 Means of escape and evacuation

Means of escape considerations include the design of doors, corridors, and stairwells while evacuation concerns the life-saving appliances used to transport passengers and crew from a ship in distress. SOLAS Chapter II-2, Part D – Escape, specifies which requirements must be met for all escape ways. For passenger ships, SOLAS specifies that the width, number, and continuity of all escapes should follow the requirements set forth in the FSS Code. Requirements for the dimensioning of stairways, doorways, and corridors are thus stipulated in Chapter 13 – Arrangement of means of escape, of that code. The same chapter also outlines evacuation routing and means of escape planning criteria. IMO's guidelines for evacuation analysis, MSC/Circ. 1033, should also be consulted for escape calculation methodology and evaluation. Specifications for life-saving appliances and arrangements for passenger ships are given in SOLAS Chapter III, Part B, Section I and Section II. Again, many of these considerations are not identical to previous SOLAS adaptations.

5.2.1 Regulatory stipulations

SOLAS and its conjunctive references provide detailed outlines for the design and designation of evacuation parameters. Broadly, the regulations are divided into two areas: one for means of escape and another for survival appliances. Means of escape criteria cover stairways and stairway enclosures, doorways, corridors, and assembly and embarkation stations. Those focusing on life saving give guidelines for both personal appliances, including life jackets and buoys, as well as craft such as life boats, life rafts, rescue boats, and marine evacuation systems. In addition to design matters, operational considerations are provided throughout. These include stipulations for staffing, training, maintenance, and inspection, among others.

For cruise ships, all spaces must have at least one escape leading to an assembly station, where passengers convene for mustering. For public spaces of more than $28m^2$, at least two escapes are usually needed. Of these, one must be designated as the primary escape and lead to a corridor, staircase, or assembly station. The secondary escape has fewer limitations, though it should not lead to the same space as the primary. In all cases, the evacuation flow should follow the generalized hierarchy shown in Figure 5.1, with routes eventually leading to life-saving craft. Though simple in concept, many additional considerations must be taken into account. Only specific spaces, for instance, can lead directly to a category 2 stair enclosure while others, including small rooms and retail spaces, must first open into a category 3 corridor.

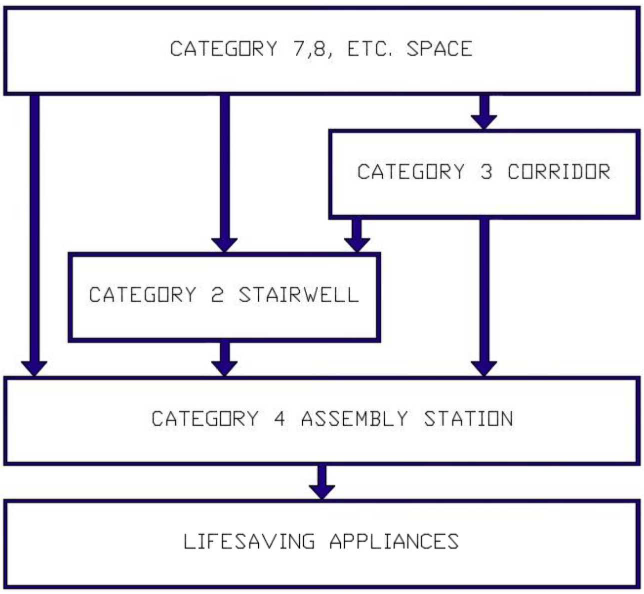

Figure 5.1. Evacuation routing

Source: based on [73]

Along with routing procedures, escape space dimensioning and life-saving appliance criteria can have significant influence on conversions, as compliance must again be proven. As with newbuilds, converted ships require documentation demonstrating that all safety considerations are met with regard to each design change.

5.2.1.1 Stairwells and stairwell enclosures

Requirements and necessary calculations for stairwell dimensions are outlined in Chapter 13 of the FSS Code. Both minimum widths and a calculation method are provided and all stairwells must comply with the more conservative of the two estimations. The minimum width for any stairwell is 900mm, with, broadly, an increase of 10mm for every person accountable in spaces designed for more than 90 persons. For such spaces, the total number of passengers expected to evacuate is taken as two thirds of the crew and one third of the passengers for which the area is designed.

The minimum width obtained must be compared with a second calculation method presented in the same chapter. This method provides minimum widths at each deck level by considering up to four decks in the direction away from the evacuation flow, according to Equation 5.1. The minimum width calculation for each deck is crucial since the width may not decrease in the direction of escape to an assembly station.

$$W = (N_1 + N_2 + 0.5N_3 + 0.25N_4) \times 10\text{mm} \tag{5.1}$$

Here, W represents the minimum required tread width between stairwell handrails and N the total number of persons expected to use the stairway during an evacuation. Subscripts represent decks, with one being the deck with the largest number of expected passengers and four the least. No more than four decks will be used in any calculation scenario. If a given deck contains excess landing space, not including space used for door openings or evacuation flow, the dimension of the calculated W variable may be reduced according to Equations 5.2 through 5.4. This is due to the assumption that a percentage of escaping passengers will take temporary refuge on the landing space.

$$P = S \times 3.0\,\text{persons/m}^2 \tag{5.2}$$

$$P_{max} = 0.25Z \tag{5.3}$$

$$N = Z - P \tag{5.4}$$

For these calculations, Z signifies the total number of persons evacuating a given deck and P the number of persons taking refuge. P is calculated with respect to the surface area of the landing space, S, though it cannot exceed one quarter of the Z value. Landing area dimensions are also stipulated, with minimum areas set to the lower of $0.1m^2$ per person or $2m^2$. The maximum landing area is $16m^2$, though this is not valid for public spaces that enter directly into a category 2 space.

All stairwell calculations must be computed for two conditions, nighttime and daytime, with the larger of the two taken as the final width. Both conditions represent conservative estimations. In the nighttime condition, all passenger berths are at maximum occupancy while crew cabins are occupied to 2/3 of their maximum capacity. The remaining 1/3 of the crew are allocated to service spaces. For daytime calculations, 3/4 of the total passenger count occupies public spaces while the crew is divided equally into thirds between public spaces, service spaces, and accommodation spaces. Expected loads for both passengers and crew are defined by the designer. For public spaces, the maximum capacity is calculated as either the number of seats or the value obtained by allocating $2m^2$ of deck area to each person.

5.2.1.2 Doorways and corridors

According to FSS Code Chapter 13, Section 2, the dimensioning of all doorways and corridors should be performed in the same manner as for stairways. Unlike stairways, however, most doors and corridors need only be dimensioned for the deck for which they serve. Therefore, the minimum dimension of 900mm and increased free width of 10mm per person for large spaces is taken, though the calculated width for a single space can be met with respect to a combination of multiple doors. Previously discussed criteria for both the maximum occupancy and daytime occupancy of public spaces are again valid. This does not include category 5 open deck spaces, however, as current regulations do not stipulate their inclusion in escape calculations.

Dimension requirements for escapes leading directly to an assembly station are stricter, as they must accommodate passengers from all evacuation routes. Therefore, the width of stairway exit doors must be no less than the aggregate width of the stairways coming from above and below the deck considered. In accordance with the FSS code, however, doors leading from an assembly to embarkation station need not be wider than 1500mm, assuming the space does not require a greater width under normal operating conditions.

5.2.1.3 Assembly and embarkation stations

As shown in Figure 5.1, today's evacuation procedures suggest that passengers be directed to assembly, or mustering, stations and not directly to lifeboat embarkation stations. Generally, they should only be escorted to survival crafts in the event of certain evacuation. An exception is in cases where an assembly station is located on the boat deck itself, meaning the assembly and embarkation stations are the same.

Guidelines for the layout, dimensioning, and positioning of stations are provided directly in SOLAS as well as the FSS Code. Assembly stations must adhere to stricter structural fire protection standards than most other categories. This applies to dual category 8/4 spaces, which are common in today's ships. Additionally, they must be located within close proximity of embarkation stations and contain a minimum deck area of $0.35m^2$ per passenger. This area requirement applies to embarkation areas also acting as assembly stations. Additional requirements regarding the positioning of embarkation stations are also specified.

5.2.1.4 Life-saving appliances

Final evacuation considerations are regulated in terms of the life-saving crafts themselves. Regulation 21 in SOLAS specifies the total capacity needed and positioning of all appliances. For cruise ships operating on long international voyages, there must be enough lifeboats to carry 37.5% of the total persons on each side. The remaining capacity, varying from 0% to 25%, can be apportioned to inflatable life rafts or marine evacuation systems. Additionally, spare rafts accounting for 25% of all persons onboard must be divided between both sides.

Additional considerations that are less imposing on conversions include the requirement that each ship side feature one rescue boat or rescue lifeboat. Specification of personal life-saving equipment is also regulated, including life buoys and life jackets. While regulated in principle, the size of lifeboats is no longer a crucial limiting factor. This is due to the aforementioned Regulation 17, which allows modern lifeboats to exceed the traditional 150-person limit as long as their safety is proven on a case-by-case basis.

5.2.2 Impact on conversions

When compared to structural fire protection, means of escape and evacuation principles impose fewer direct impacts on conversions. While more difficult to quantify, however, conversion designs must still comply with all safety and evacuation criteria and can result in both physical and operational alterations. Structurally, the addition of category 3 corridors to specific conversion areas are likely, especially if a category 8 public space is converted into various category 7 spaces, including cabins. This is due to the requirement that the primary exit lead directly to, in most cases, a corridor. When partially replacing a former space with a corridor, the perimeter boundaries may require strengthening in terms of fire integrity and new escape calculations and evacuation plans must be produced.

Also possible is the necessitation of a widened escape. Taking the same example where a former public space is converted into a cabin area, the resulting calculations for the night condition may require a wider free escape width than the former daytime calculation. The same could occur for a cabin area situated in a likely conversion space. If converted to one or more public spaces, the new daytime condition could be a limiting factor. These scenarios are less likely that the comparatively simple addition of corridors, though their implications on conversions are far greater.

The conversion of a public space to cabin area, which is currently the most probable case, also carries direct implications in terms of evacuation procedures. Since mustering stations are designed for an assumed number of escaping persons, altering the capacity of a main fire zone or area can significantly affect mustering plans. For a large number of additional cabins, as seen with *Carnival Sunshine*, resulting changes can be substantial. At the least, many cabins will need to be reassigned to a new assembly station in order to make room for the new ones. This can result in what is virtually a complete rework of the original mustering calculations, as the evacuation flow from each cabin, both existing and new, must follow strict regulatory guidelines. An even more demanding scenario would be one in which the desired occupancy increase exceeds the ship's assembly station or lifesaving limits. Adding new lifeboats would be a serious challenge due to the limited area over which they can be placed.

Designating an existing space as a new assembly station can also require significant investment. With respect to fire protection, category 4 spaces are often subject to stricter requirements than a category 8 space of identical design. As such, the replacement of deck and bulkhead insulation could be dictated even though the space in question is not physically altered. The materials used to outfit the space in question may also be inadequate for the new designation. Specifically, in accordance with SOLAS regulation II-2 and the FSS and FTP Codes, the floor coverings of public spaces used as internal mustering stations must meet stricter smoke, toxicity, and surface flammability requirements. The same regulations also outline test procedures that can be followed to prove a given material's compliance. In addition to this, assembly stations must adhere to stricter ventilation requirements than an equivalent category 8 public space.

5.3 Stability

A vessel's stability represents a different type of issue than either its structural fire protection or escape and evacuation. While all three are crucial for the safe operation of a cruise ship, stability has broader implications on a vessel's performance, service life, and safety. Whereas the latter two disciplines are considered during later stages of initial design, stability must be considered in the earliest concept design stages. Because ship stability is, on the base level, a result of its geometry, poor stability results can greatly affect earlier decisions including the main design dimensions. Fire integrity of non-crucial members and detailed escape design can be developed in detail after a vessel's principle characteristics have been confirmed. As such, stability is included in the first cycle of a traditional ship design spiral while the other disciplines are the focus of secondary iterations. Some key arrangement principles, however, including corridor and stairwell placement, can greatly affect the damage stability in particular. This is due to the need for large openings to be arranged as close to the centerline as possible in order to reduce the risk of submergence in a listing scenario. This illustrates the interconnected and iterative design process for all ships, but especially for those as complex as modern cruise vessels.

5.3.1 Regulatory stipulations

As a concept design consideration, stability is not solely a regulatory concern. Basic naval architectural principles are first followed in order to produce a reasonable design that can then be evaluated with regard to the stipulated rules. Once the design reaches detailed stages, however, many stability cases must be checked. There are various guidelines for both intact and damage stability and a vessel's specific requirements will vary according to factors including its mission or operating region. For cruise ships, IMO compliancy must be verified for a range of criteria.

Intact stability, as summarized in Chapter 3.1.4, must be sufficient for many loading conditions and potentially for many standards. Example conditions include the primary two, departure and arrival, as well as intermediate conditions representing different stages of a voyage. The departure condition describes the case where a ship is beginning its voyage. General assumptions therefore include full or nearly full passenger, store, lubrication oil, and fuel oil capacities and empty garbage-handling loads, among others. The near opposite is true for the arrival condition, not including the passenger load, which is still at the same capacity. Transitional conditions vary according to the estimated duration of the voyage and time of evaluation. The vessel must have an adequate GM to ensure stability in each case assessed. This represents only a basic summary of requirements, as in reality there are many more cases and conditions, such as weather or passenger crowding, to be considered.

Damage stability must be evaluated to ensure an adequate safety level in the event of an accident or collision. Again, various cases must be investigated and recent regulatory amendments have made this an intensive process. Loading and damage cases must be covered for a wide array of scenarios, yielding an extensive amount of damage combinations to be considered. Again, the details of such calculations are beyond the scope of the present thesis and could easily form the basis of their own study. The principles are important, however, and must be covered in order to suggest a reasonable solution with regard to conversions. In essence, the fundamental requirement for both intact and damage stability is that a ship meet stipulated GM limits for the varying cases and conditions mentioned. This again emphasizes the importance of a cruise ship's metacentric height in both newbuild and conversion engineering. This simplified principle is illustrated in Figure 5.2, which outlines a scenario in which a ship meets the basic stability requirements for all prescribed loading conditions. In this case, a new vessel is studied with probabilistic damage stability; corresponding figures for older ships will demonstrate different trends even though the same theory is applicable.

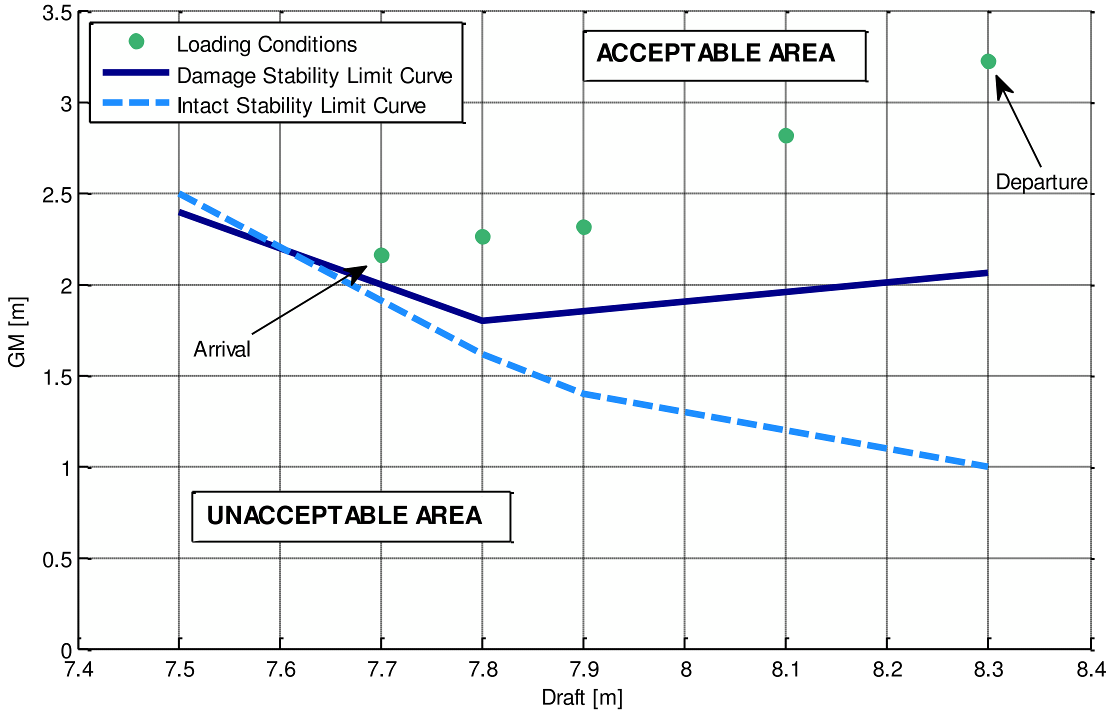

Figure 5.2. GM stability limit curves

Source: based on [73]

5.3.2 Impact on conversions

As previously covered, initial stability results like those shown in Figure 5.2 cannot be assumed for a ship's post-conversion condition. Even if major conversion weights are not added during drydock, increment weight gain over time yields new stability characteristics. Therefore, a vessel's current stability characteristics should always be verified. This requires analysis beforehand and as such has a direct impact on conversions even if a major alteration such as a sponson-ducktail is not chosen.

When deciding whether to correct diminished stability characteristics, many factors are taken into account. Ultimately, the addition of a sponson-ducktail has large implications on both a vessel's future service life and present conversion costs. The primary advantage is improvement in stability and potentially brand or service life. Figure 5.3 provides an example of a cruise ship's stability characteristics before and after the addition of a sponson-ducktail and conversion. Results will naturally vary according to the ship and scope of the project, but the sample results are representative for a post-conversion vessel.

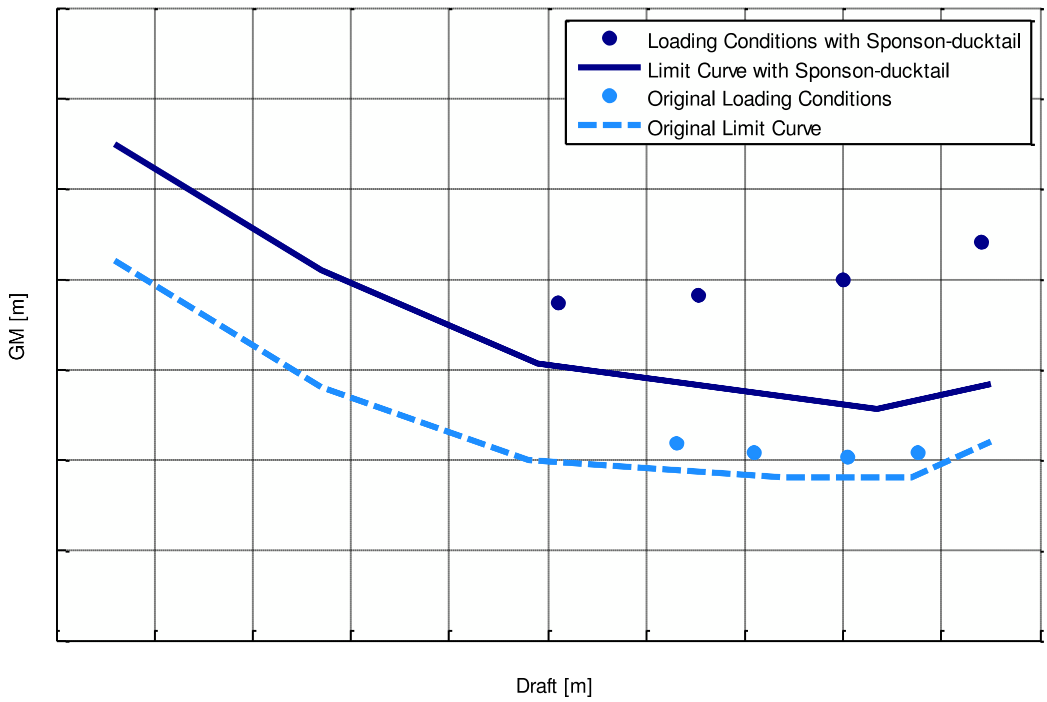

Figure 5.3. Sample post-conversion stability comparison
Source: based on [73]

The aforementioned GM increase is evident in this case, where the post-conversion loading conditions are much less critical than before. Also evident is the change in the regulated limit curve, since major hull form modifications affect the stability requirements and calculations. Therefore, the GM increase alone does not assure an improvement. Rather, the relationship between the increased GM and the similarly increased stability limits determines the success of a sponson-ducktail.

Results like those shown in Figure 5.3 have popularized sponson-ducktails but their high initial costs can still be a deterrent. In this way, the impact on conversions is expounded, since it will increase costs and prolong planning and conversion times. Though detailed cost data is sparse, a baseline estimate of approximately 15 USD/kg is reasonable. For a typical ducktail weighing 300 tons, this can result in a direct acquisition cost of 4 million USD or more, depending on vessel size and severity of weight proliferation. Neither all planning costs nor increased off-hire time are included in such an estimate, however. For a typical cruise operator and ship, the total sponson-ducktail cost can correspond to a payback period of three years [79], though even longer periods are probable. These investment concerns likely deter many operators from including hull form changes in conversion plans, even for ships such as

Carnival Sunshine, whose conversions feature an exorbitant amount of added weight and volume. Even so, events since the ship's relaunch, including major itinerary and deployment changes [94], suggest that the omission of the appendage is evident in operation.

5.4 Summary

The conversion cases identified in Chapter 4 are to be studied with respect to three conversion disciplines: structural fire protection, means of escape and evacuation, and stability. Though not exhaustive, these disciplines represent major considerations that must be taken into account before finalizing any conversion plans. All three considerations have significant implications during the initial design phases, with regard to both naval architectural principles and governing rules. By investigating what is stipulated by relevant regulations, provident initial design measures can be recommended in the following chapter.

6 Proposing initial design solutions

The next goal of the study is to answer the final sub-research question. This chapter identifies what, if anything can be considered during design stages in order to reduce the identified conversion tasks' impact on a project. The specific conversion challenges introduced in the preceding chapter are studied alongside the initial design implications and conversion disciplines. This yields explicit recommendations for each conversion case with respect to all three disciplines, where applicable. The structure of this chapter will follow the last, with initial design approaches divided first according to conversion discipline and then case.

6.1 Structural fire protection

Fire integrity's most direct conversion impact involves the renovation of structural boundaries for SOLAS compliance. In order to reduce planning efforts, costs, and timing associated with the actual conversion work, such upgrading of deck and bulkhead insulation should be avoided entirely. Arrangement principles should therefore stipulate conservative measures with regard to fire integrity. However, a balance should be achieved since taking overly conservative measures will lead to excessive preliminary costs. The final recommendations should therefore be specific enough to avoid an unreasonably expensive and redundant vessel design. As such, suggesting that all boundaries within a probable conversion area be upgraded would be a simplistic and unfeasible solution for the fire integrity challenges.

With this in mind, the aim is to compile a detailed list of scenarios that benefit from initial conservative classifications. This is completed for each conversion case featuring arrangement modifications. As a starting point, Table A 18, adapted from SOLAS boundary tables, provides the structural requirements for all orientation scenarios, both vertically and horizontally. This makes for convenient comparisons by taking a space in question, determining its probable conversion scenario, identifying its bordering spaces, and contrasting the before-and-after boundary requirements. Using this table, limiting categories are defined for each conversion case and separate tables are created to illustrate the specific requirements needed for any given case. These are compiled into Table 6.1 through Table 6.4.

Table 6.1 Case 1 Comparison

Source: adapted from Table A 18

CAT 8 → 3			
	8	→	3
Below 1	A-60	→	A-15
Above 1	A-30	→	A-15
Beside 1	A-60	→	A-0
Below 2	A-15	→	A-0
Above 2	A-0	→	A-0
Beside 2	A-15	→	A-0
Below 3	A-15	→	A-0[a]
Above 3	A-15	→	A-0[a]
Beside 3	B-15	→	B-15
Below 4	A-60	→	A-60
Above 4	A-0	→	A-0
Beside 4	B-15	→	A-60
Below 5	A-0	→	A-0
Above 5	A-0	→	A-0
Beside 5	A-0	→	A-0
Below 6	A-15	→	A-0
Above 6	A-0	→	A-0
Beside 6	B-0	→	B-15
Below 7	A-15	→	A-15
Above 7	A-15	→	A-15
Beside 7	B-0	→	B-15
Below 8	A-30	→	A-15
Above 8	A-30	→	A-15
Beside 8	B-0	→	B-15
Below 9	A-0	→	A-0
Above 9	A-0	→	A-0
Beside 9	C	→	B-15
Below 10	A-0	→	A-0
Above 10	A-0	→	A-0
Beside 10	A-0	→	A-0
Below 11	A-0	→	A-0
Above 11	A-30	→	A-60
Beside 11	A-30	→	A-15
Below 12	A-0	→	A-30
Above 12	A-60	→	A-60
Beside 12	A-60	→	A-30
Below 13	A-0	→	A-0
Above 13	A-30	→	A-15
Beside 13	A-15	→	A-0
Below 14	A-0	→	A-30
Above 14	A-60	→	A-60
Beside 14	A-60	→	A-30

Table 6.2 Case 2 Comparison 1

Source: adapted from Table A 18

CAT 3 → 8			
	3	→	8
Below 1	A-15	→	A-60
Above 1	A-15	→	A-30
Beside 1	A-0	→	A-60
Below 2	A-0	→	A-15
Above 2	A-0	→	A-0
Beside 2	A-0	→	A-15
Below 3	A-0[a]	→	A-15
Above 3	A-0[a]	→	A-15
Beside 3	B-15	→	B-15
Below 4	A-60	→	A-60
Above 4	A-0	→	A-0
Beside 4	A-60	→	B-15
Below 5	A-0	→	A-0
Above 5	A-0	→	A-0
Beside 5	A-0	→	A-0
Below 6	A-0	→	A-15
Above 6	A-0	→	A-0
Beside 6	B-15	→	B-0
Below 7	A-15	→	A-15
Above 7	A-15	→	A-15
Beside 7	B-15	→	B-0
Below 8	A-15	→	A-30
Above 8	A-15	→	A-30
Beside 8	B-15	→	B-0
Below 9	A-0	→	A-0
Above 9	A-0	→	A-0
Beside 9	B-15	→	C
Below 10	A-0	→	A-0
Above 10	A-0	→	A-0
Beside 10	A-0	→	A-0
Below 11	A-0	→	A-0
Above 11	A-60	→	A-30
Beside 11	A-15	→	A-30
Below 12	A-30	→	A-0
Above 12	A-60	→	A-60
Beside 12	A-30	→	A-60
Below 13	A-0	→	A-0
Above 13	A-15	→	A-30
Beside 13	A-0	→	A-15
Below 14	A-30	→	A-0
Above 14	A-60	→	A-60
Beside 14	A-30	→	A-60

Table 6.3 Case 2 Comparison 2

Source: adapted from Table A 18

CAT 7 → 8			
	7	→	8
Below 1	A-60	→	A-60
Above 1	A-15	→	A-30
Beside 1	A-60	→	A-60
Below 2	A-15	→	A-15
Above 2	A-0	→	A-0
Beside 2	A-15	→	A-15
Below 3	A-15	→	A-15
Above 3	A-15	→	A-15
Beside 3	B-15	→	B-15
Below 4	A-60	→	A-60
Above 4	A-0	→	A-0
Beside 4	B-15	→	B-15
Below 5	A-0	→	A-0
Above 5	A-0	→	A-0
Beside 5	A-0	→	A-0
Below 6	A-0	→	A-15
Above 6	A-0	→	A-0
Beside 6	B-0	→	B-0
Below 7	A-15	→	A-15
Above 7	A-15	→	A-15
Beside 7	B-0	→	B-0
Below 8	A-15	→	A-30
Above 8	A-15	→	A-30
Beside 8	B-0	→	B-0
Below 9	A-0	→	A-0
Above 9	A-0	→	A-0
Beside 9	C	→	C
Below 10	A-0	→	A-0
Above 10	A-0	→	A-0
Beside 10	A-0	→	A-0
Below 11	A-0	→	A-0
Above 11	A-15	→	A-30
Beside 11	A-15	→	A-30
Below 12	A-0	→	A-0
Above 12	A-60	→	A-60
Beside 12	A-60	→	A-60
Below 13	A-0	→	A-0
Above 13	A-30	→	A-30
Beside 13	A-15	→	A-15
Below 14	A-0	→	A-0
Above 14	A-60	→	A-60
Beside 14	A-60	→	A-60

Table 6.4 Case 3 Comparison

Source: adapted from Table A 18

CAT 5 → 8			
	5	→	8
Below 1	A-0	→	A-60
Above 1	A-0	→	A-30
Beside 1	A-0	→	A-60
Below 2	A-0	→	A-15
Above 2	A-0	→	A-0
Beside 2	A-0	→	A-15
Below 3	A-0	→	A-15
Above 3	A-0	→	A-15
Beside 3	A-0	→	B-15
Below 4	A-0	→	A-60
Above 4	[-]	→	A-0
Beside 4	A-0	→	B-15
Below 5	[-]	→	A-0
Above 5	[-]	→	A-0
Beside 5	[-]	→	A-0
Below 6	A-0	→	A-15
Above 6	A-0	→	A-0
Beside 6	A-0	→	B-0
Below 7	A-0	→	A-15
Above 7	A-0	→	A-15
Beside 7	A-0	→	B-0
Below 8	A-0	→	A-30
Above 8	A-0	→	A-30
Beside 8	A-0	→	B-0
Below 9	A-0	→	A-0
Above 9	A-0	→	A-0
Beside 9	A-0	→	C
Below 10	A-0	→	A-0
Above 10	A-0	→	A-0
Beside 10	A-0	→	A-0
Below 11	A-0	→	A-0
Above 11	A-0	→	A-30
Beside 11	A-0	→	A-30
Below 12	A-0	→	A-0
Above 12	A-0	→	A-60
Beside 12	A-0	→	A-60
Below 13	A-0	→	A-0
Above 13	A-0	→	A-30
Beside 13	A-0	→	A-15
Below 14	A-0	→	A-0
Above 14	A-0	→	A-60
Beside 14	A-0	→	A-60

Each of the three arrangement-based conversion cases are broad and cover an array of potential conversion possibilities. The first case, large public space conversions, can involve the division of a large space into a cabin area or smaller public spaces. The same is true for the small public space or cabin area conversion, as it covers the expansion into one or multiple larger spaces. Finally, for the open deck conversion scenario, the category 5 space can be converted into a multitude of other categories, including category 7 cabins or category 8 public spaces, among others. Therefore, certain assumptions are made to produce generalized suggestions for each case.

6.1.1 Large public space conversion

The first and most probable conversion case represents a single space being divided into multiple new ones, as shown in Appendix D, case 1. The most likely scenario is for a former category 8 space to be converted into a cabin area primarily consisting of category 7 staterooms and category 3 corridors. A second scenario is for such a space to be converted into smaller public spaces of either category 7, category 8, or a combination. The effect of this type of conversion on subdivision criteria can be deceiving, as a category 8 space is already one of the most conservatively governed integrity categories. When being converted solely into smaller category 8 spaces, no upgrade is required since no category change takes place. This does not account for the new dividing bulkheads, which must be of a proper integrity. Even this, however, is often avoided by following a specific exemption rule regarding openings. If perimeter boundaries between the added and existing spaces are at least 30% open, the added partial bulkheads are exempt from SOLAS integrity considerations. When being converted into even smaller spaces, either cabins or category 7 public spaces, however, certain boundaries must be checked.

Though a category 8 space will always have a greater or equal integrity than a category 7, the category 3 corridors that separate such small spaces must be investigated. Principally, a room cannot be designed with a primary escape into another room. Therefore, whether cabins or smaller public spaces are added, corridors will nearly always be needed as a means of escape. This can again be avoided for public spaces following the 30% open criteria but never for a new cabin area. Since a corridor represents the only probable and easily predictable conversion space requiring strengthening, it is taken as the limiting category for the first conversion case. Table 6.1 lists the category 8 and 3 integrity comparisons for every potential orientation. The table is color coded to allow for a simple comparison, using the criteria listed in Table 6.5.

Table 6.5 Integrity comparison levels

already in compliance	lower integrity stipulated
	same integrity stipulated
boundary strengthening required	single integrity increase needed
	double integrity increase needed
	triple or more integrity increase needed
N/A	not applicable

When comparing a former category 8 room with a new category 3 corridor, the existing boundaries will be compliant in most orientation scenarios. Of the 42 potential arrangement situations, only eight require upgrades. Some of these, however, are not probable and are neglected for various reasons. Category 6 spaces, accommodation spaces of minor fire risk, are virtually nonexistent aboard modern cruise ships. For such a category, all furniture included must be of a strict design that is not feasible for either crew or passenger spaces. With respect to arrangement, the scenarios where a convertible category 8 space is oriented below either a category 11 or category 14 space are also rare. As identified in Chapter 4, the most probable conversion areas for large passenger spaces include the upper, fore and aft sections of a ship. Even where a lower space is converted, however, large public spaces such as a theater or dining room are rarely above an auxiliary machinery or cargo space of category 11. An orientation below a category 14 space, in which flammable liquids are stowed, is also neglected due to both the unlikelihood and impact of the situation, though some spaces like paint lockers, liquor stores, or perfume stores may be present. With these omissions, five strengthening scenarios remain.

Only one of the remaining scenarios, and likely the least probable, concerns deck insulations. This is the case where a category 8 space is converted into a category 3 space when below a category 12 galley. If a category 8 space in a probable conversion area is below this, the intermediate deck insulation should be upgraded from class A-0 to A-30 to avoid reinforcement. Though the category 8 space will be large, the area underneath a galley likely includes only a portion, meaning the cost increase may not be significant.

The remaining cases are more likely and concern bulkhead replacements. Specifically, if the perimeter bulkhead of a category 8 space in a probable conversion area borders a category 4 assembly station or another category 7 or 8 space, an increase from B-0 to B-15, for the latter, or A-60, for assembly stations, is warranted. Of these possibilities, the category 7 or 8 border is much more likely.

The final scenario involves an adjacent category 9 space, which is generally either a water closet or pantry. This differs from the previous cases because of the general laxity regarding this category, as C material is generally the only stipulated integrity requirement. This implies that, regardless of what type of conversion occurs in or around a category 9 space, upgrading will almost certainly be required. For this reason, it would be beneficial to insulate these spaces conservatively when located within probable conversion zones. For pantries to be classified as category 9, only restricted appliances can be stored. For the allowed appliances, strict power limits are mandated. This differs from a category 13 pantry, which requires A divisions and may contain limited cooking equipment with greater power. Therefore, by avoiding all category 9 pantries and opting for category 13 instead, conversions become simpler and the pantries themselves become more versatile.

In summary, there are four main arrangement recommendations for large public spaces arranged within an identified probable conversion area:

i. *Upgrade upper deck insulation from A-0 to A-30 if the existing category 8 space is below a category 12 galley.*
ii. *Upgrade perimeter steel bulkhead insulation from B-0 to B-15 if the existing category 8 space borders a category 7 or another category 8 space.*
iii. *Avoid category 9 pantries entirely, designating them instead as more flexible category 13 pantries.*

6.1.2 Small public space or cabin area conversion

The second conversion case represents the reverse of the first. Here, multiple smaller spaces are combined into a single, larger public space, as shown in Appendix D, Case 2. In terms of fire integrity, this generally implies that multiple category 7, 8, and 3 spaces are combined into a single category 8 area, though other categories, such as pantries, may be involved as well. Unlike the first case, two primary scenarios must be taken into account for this type of conversion. With certain arrangement orientations, the insulation dividing both a category 3 and category 7 space requires improvements, but to varying degrees. Therefore, both are considered and shown in Table 6.2 and Table 6.3, respectively.

Of the two situations, the conversion of a category 3 space more commonly necessitates upgraded boundaries. Of the scenarios shown in Table 6.2, fifteen require enhancements, though some bearings are again improbable. Orientations that are more probable include those in which the category 3 space in question is adjacent to a category 1 space, such as the navigation bridge, or a category 2, 3, 8, 12, or 13 space. The most probable cases include a corridor located above the bridge, below or above another corridor, and below or above a category 8 space. Each of these placements requires an increase from either an A-15 boundary to A-30 or A-30 to A-60.

Potential category 7 spaces that may be converted into a category 8 include small public rooms or cabins. Generally, these are placed near other public areas, as the conversion of cabin areas on accommodation-only decks are improbable. The implications of a category 7 to category 8 conversion are not as significant and always feature deck enhancements as opposed to bulkhead. Once improbable placements are neglected, three situations should be considered. These are a current category 7 space above a category 1 space as well as below or above a category 8 space. For each of these situations, an upgrade from an A-15 insulated deck to an A-30 will eliminate the need to replace insulation during drydock.

As before, eliminating the use of category 9 pantries will reduce the effect of smaller spaces on the conversion process. A category 13 space that is converted to a category 8 will require new insulation in only 4 scenarios in comparison to the 25 required when converting a category 9 space to a category 8. With this and the previously mentioned circumstances, the following recommendations are valid for the second conversion case. Where the first conversion case focuses on bulkhead integrity, the second features more deck considerations.

i. *Upgrade the boundary integrity of category 3 spaces within probable conversion areas. The most prominent upgrade cases include spaces above the bridge, above or below a corridor, and above or below a large public space.*
ii. *For cabins or small public spaces in probable conversion areas, upgrade the deck integrity from A-15 to A-30 if above the bridge, above a large public space, or below a large public space.*
iii. *Continue to replace category 9 pantries with category 13.*

6.1.3 Outer deck conversion

The conversion of a category 5 space into enclosed spaces, as shown in Appendix D, Case 3, represents the final arrangement case and therefore the final case to be considered for structural fire integrity. When considering a provident initial insulation selection, it is impossible to know the exact extent of a future conversion. Today, the prominent trend is to convert upper, forward and aft open deck spaces into cabin areas, though conversions into category 8 public spaces have also occurred. With such uncertainty, it is best to use conservative selection principles in order to cover all conversion bases, which means designating the insulation to correspond to the strictest requirements between a category 3, 7, and 8 conversion. Between the three, the category 8 scenario is always the most stringent for an open deck space above another area in question. Category 8 is thus chosen as the limiting conversion factor. If a category 5 boundary is insulated with respect to a category 8 space, it will always be in compliance for the other two categories. Table 6.4 lists the fire boundary comparisons for this conversion case.

Probable conversion areas for this case are limited to forward and aft open deck spaces. The orientations shown in Table 6.4 are reduced even further, as only those for which an open deck space is above another should be considered. As such, only lower deck insulation requires a conservative design for open deck conversions. Specifically, upgrades are advantageous if the deck is above the bridge, a corridor, a cabin, a public space, or a galley, as each of these is common. The level of increase varies according to the space below, with a stipulated A-0 deck requiring an increase to either an A-15, A-30, or A-60 class. These represent an open deck being arranged above a corridor or cabin, the bridge or large public room, or galley, respectively. Even for the latter, an increase in initial design costs should be nominal due to the limited area in question. The implications on conversions are significant, however, due to the growing popularity of this conversion case. The specific situations that are most probable and therefore warrant consideration are summarized below.

i. *If an upper, fore or aft open deck space is arranged above a corridor or category 7 room, upgrade the intermediate deck insulation from A-0 to A-15.*
ii. *If above a large public space, upgrade the insulation from A-0 to A-30.*
iii. *If above a category 12 room or galley, upgrade the insulation from A-0 to A-60.*

6.2 Means of escape and evacuation

Principle conversion setbacks due to means of escape and evacuation are related to minimum required escape widths and life-saving capacities. These challenges can be addressed at the initial design stage through both arrangement principles and conservative margin allowances. The aim is to identify provident measures that reduce or eliminate the need to increase escape widths, add supplemental lifesaving equipment, or replace steel or outfitting materials. Each could be mandated by a future capacity increase or redesignation of a space's function.

6.2.1 Large public space conversion

There are two key insinuations regarding the first conversion case and means of escape. The first is the widening of escape ways that may be necessary when converting an existing space into, most likely, a cabin area. The second is the implied capacity increase for such a conversion. Though significant increases in base capacity are difficult due to the physical restraints of a vessel, the reference conversions demonstrate the desire to increase a vessel's capacity as much as feasibly possible. This type of redesign and capacity increase therefore has compounded effects on escape procedures and evacuation calculations.

For initial calculations, special attention should be placed on large public spaces within probable conversion areas. Specifically, conservative calculations should be executed to ensure that existing dimensions are adequate for both the proposed design and probable future conversion designs. In correspondence with Chapter 5.2.1.1, one parameter that affects calculations is the estimated number of persons occupying a given space. As covered, SOLAS stipulates that calculations be performed for both a daytime and nighttime condition. For public spaces, the number of persons expected to evacuate from any given public space is taken as either the number of seats or the value equal to $2m^2$ of the gross surface area per person. For the daytime condition, ¾ of the maximum capacity is assumed to be occupying each space at all times, while all passengers are allocated to cabins for nighttime calculations.

Case 1 features a public space being divided into a cabin area and the initial daytime calculations are therefore always more conservative than the conversion ones. For the night condition, however, a cabin area will mandate wider means of escape and widening is required if the new night calculations are greater than the initial daytime ones. This is especially problematic for upper deck areas, as the stairway width cannot decrease along the path to assembly stations. Therefore, should an upper stairway need widening, all lower stairs are subject to the same considerations. The result could thus influence large areas of the vessel and, should such modifications be necessary, the proposed conversion design would likely be discarded due to the cost and time required for such extensive restructuring.

To reduce the probability of such a modification, conservative nighttime escape calculations should be carried out during the initial design phase. Since passenger cabins are now built as modules and homogenized across a vessel, an estimation of the potential amount of added passenger cabins can be made with little uncertainty. Allocating similarly sized cabins to a public space within an identified conversion area will yield a strong approximation for the number of persons and cabins that can later occupy a public space of the same size. By taking the result as an input for the nighttime condition, suggested widths can be compared to the current design. If more conservative, the newly calculated widths should be used as minimum values to ensure an easy conversion in the future. Even if a major conversion is not chosen for the space in question, a conservative estimate will still enhance the flexibility of the space. Since calculations are often dependent on the number of seats, even small refurbishments with new seating arrangements may alter the capacity and therefore all calculations.

In addition to calculations, margins can be applied for the overall passenger count and lifesaving equipment needed, as outlined in Chapter 5.2.1.4. This simplifies conversion projects by eliminating the need to add new lifeboats or rafts or reroute mustering plans due to an increased passenger load. When cabins replace a former public space, the occupancy of the fire zone in question increases. Even if there are enough life-saving appliances on board, this likely necessitates new mustering calculations since the assembly and evacuation stations serving the affected zone were designed with respect to the original load. Should new cabins create an excess in overall passenger count, even more calculations and conversion changes would be required in order to incorporate new lifeboat, tender, or raft equipment into existing mustering spaces. The availability of extra space is not guaranteed and the preparatory design work would be extensive. This work and the associated costs of the preparation and execution of such modifications can be greatly reduced by including a buffer for both the overall craft and station capacities. A suitable margin should vary by operator, based on past conversions. *Brilliance of the Seas*, for instance, featured a post-conversion double occupancy increase of less than 2% while *Carnival Sunshine* increased the same value by 14%.

One final consideration is the designation of assembly stations. While embarkation stations are limited to the areas surrounding evacuation craft, assembly stations can be located on either the promenade deck or nearby public spaces. Again, existing assembly stations may prove inadequate for the post-conversion cabin count and additional spaces can therefore be set aside at the initial design stage for potential reclassification later. For passengers, the differences between a category 8 space and a dual category 8/4 space are negligible, though they can be significant for designers and engineers. The most obvious difference concerns the structural fire integrity of the space in question. As shown in Table 6.6, an interior assembly station requires more stringent boundary insulation in many scenarios. The insinuation of these differences is the same as those discussed earlier, since the redesign and replacement of affected boundaries can be time consuming and expensive at the conversion stage.

Table 6.6 Assembly station integrity comparison

Source: adapted from Table A 18

	CAT 8 → 8/4		
	8	→	8/4
Below 1	A-60	→	A-0
Above 1	A-30	→	A-0
Beside 1	A-60	→	A-0
Below 2	A-15	→	A-0
Above 2	A-0	→	A-0
Beside 2	A-15	→	A-0
Below 3	A-15	→	A-0
Above 3	A-15	→	A-60
Beside 3	B-15	→	A-60
Below 4	A-60	→	A-0
Above 4	A-0	→	A-0
Beside 4	B-15	→	[-]
Below 5	A-0	→	[-]
Above 5	A-0	→	A-0
Beside 5	A-0	→	A-0
Below 6	A-15	→	A-0
Above 6	A-0	→	A-60
Beside 6	B-0	→	A-60[b,d]
Below 7	A-15	→	A-0
Above 7	A-15	→	A-60
Beside 7	B-0	→	A-60[d]
Below 8	A-30	→	A-0
Above 8	A-30	→	A-60
Beside 8	B-0	→	A-60
Below 9	A-0	→	A-0
Above 9	A-0	→	A-0
Beside 9	C	→	A-0[d]
Below 10	A-0	→	A-0
Above 10	A-0	→	A-0
Beside 10	A-0	→	A-0
Below 11	A-0	→	A-0
Above 11	A-30	→	A-60
Beside 11	A-30	→	A-60[b]
Below 12	A-0	→	A-0
Above 12	A-60	→	A-60
Beside 12	A-60	→	A-60[b]
Below 13	A-0	→	A-0
Above 13	A-30	→	A-60
Beside 13	A-15	→	A-60[b]
Below 14	A-0	→	A-0
Above 14	A-60	→	A-60
Beside 14	A-60	→	A-60[b]

These differences are not only significant in quantity, but also in the extent of required replacement. For all orientations, it is only the deck above and surrounding bulkheads that require consideration, but the level of increase is much higher than those from previous cases. For common scenarios, deck insulation upgrades of two to three classes are needed, while bulkheads must often be modified from B to A boundaries. For decks, the most probable scenarios include the orientation of a public space above a corridor, cabin area, or category 8 space. Bulkheads adjacent to corridors, cabins, public spaces, and both category 9 and 13 rooms should also take precedence in initial design concerns. Changes can again be reduced by eliminating the use of category 9 pantries in favor of more flexible ones.

Along with structural fire integrity, there are a few key outfitting differences between a public space and an interior assembly station. As highlighted in SOLAS, the FTP code, and IMO MSC publications, assembly stations must meet stricter requirements with respect to acceptable materials. Explicitly, all floor covering materials used in assembly stations must be tested for smoke and toxicity durability in addition to surface flammability. By ensuring that all potential assembly stations meet structural fire protection and outfitting guidelines, future designation will be a simple matter rather than a major conversion concern.

In summary, to minimize the effects of a large public space conversion on means of escape criteria, the following initial design guidelines can be taken into account.

i. *Design conservative evacuation plans. For a public space within a probable conversion area, calculate necessary escape widths with respect to an additional case corresponding to the estimated cabin capacity that the space in question can hold. Particular attention should focus on the nighttime condition and upper deck spaces.*

ii. *Include margins for the total number of persons carried and resulting lifesaving capacity. Margins can be estimated based on previous conversion trends.*

iii. *Design and outfit suitable large public spaces in line with IMO assembly station requirements. Both fire protection and surface materials should be upgraded.*

6.2.2 Small public space or cabin area conversion

Unlike conversion case one, the conversion of cabin areas or small public rooms into a larger space does not suggest an increase in overall capacity. This eliminates similar lifesaving and assembly station considerations. The most significant escape considerations therefore solely concern calculated dimensions.

Initial escape planning should be executed in an opposite manner as previously covered. In contrast to the large public space conversion, the conversion of smaller spaces, including cabins, into a single public space can potentially affect dimensions by increasing the minimum calculated widths for the day condition. Here, widening of any means of escape could be mandated, should the expected number of persons in the new public space in the day condition exceed the nighttime estimate for the previous cabin area. To minimize the chance of this occurring, this third condition can be included in initial calculations.

After taking the surface area of the probable conversion space, an approximate $2m^2$ per person can be used to estimate the number of expected passengers in a public space of equal size. Since this is a load indicator in SOLAS, the calculated value should yield a respectable estimate. This should only be completed if a cabin area is located in a space that would be ideal for a future public area, such as an upper deck space near other public ones. For such a scenario, taking the most conservative of the new and existing calculations will cover all bases for future conversions. This recommendation for the second conversion case is summarized below.

i. Identify cabin areas that occupy spaces in prime public space areas. For these, implement a conservative evacuation calculation procedure by introducing a third case in which a public space of equal size replaces cabins for each scenario. Particular attention should focus on the daytime condition and upper decks.

6.2.3 Outer deck conversion

The outer deck conversion case is similar to the first in that it often, though not always, implies that the vessel's capacity, or at least cabin count, will be increased. As such, the same suggestions regarding margins for the total lifesaving capacity and equipment are valid for the third conversion case. Large differences, however, revolve around the dimensioning of escape ways and the prescribed SOLAS methods used.

Currently, SOLAS does not require category 5 spaces to be included in evacuation routing calculations. The planning for a conversion that encloses such a space is therefore more intense than for the latter conversion cases, at least in terms of escape calculations. Whether the open deck is converted to a cabin area or public space, completely new calculations must be performed. As previously mentioned, the fact that the spaces in question are confined to the upper decks can potentially compound the situation, since no stairwell dimension can be reduced on lower decks leading to an assembly or embarkation station.

To combat this potential challenge, suitable open deck spaces should be roughly approximated in initial design calculations. For structural fire protection, an assumed category 8 is taken as a conservative measure, though both the category 8 and combined category 7 and 3 cabin scenarios should be considered for means of escape. For the possibility of a future enclosed public space, the same $2m^2$ figure can be used to estimate the number of intended passengers, while the same figure for an enclosed cabin area should be based on existing cabin sizes. By considering each scenario, both the daytime and nighttime conditions should be checked with respect to all dimensions. Aside from the previously covered capacity margins, the initial design recommendations for this conversion case are therefore summarized as follows:

i. *Include upper open deck spaces, located forward and aft, in initial escape calculations even though SOLAS does not stipulate their consideration. As a conservative approach, estimate the expected passenger load for both a public space and cabin area of the same size. With these expected loads, calculate the minimum dimension requirements for both day and night conditions.*

6.3 Stability

Where fire integrity and escape challenges can be addressed through arrangement principles and allowances, poor stability development and its avoidance centers solely around weight and margin concerns. The suggested stability practices also only affect the final conversion case, or weight additions. Ultimately, the most direct solution is straightforward. By including adequate margins in initial weight estimations and subsequent iterations, both unexpected and planned weight growth, along with KG changes and affected stability, can be proactively compensated for. Though simple to define, however, additional decisions regarding the application of such margins are more complex and uncertain.

Commonly, weight-related margins are divided into two categories: acquisition, or shipyard, margins and service life allowances. The latter represents allowances included in weight estimates to offset inherent precision limitations in early design. They can be introduced as both weight and KG allowances. This is important due to the uncertainties of initial design, where weight calculations slowly transform from estimations to measurements. It is only after the building and detail design phases have begun that a true weight estimation evolves, though some values are still projected rather than weighed. The second type of reserve, service life allowances, is included to compensate for changes to a vessel's specifications throughout its lifecycle, including the inherent growth and conversion weights that are common for cruise ships. The goal for this reserve is to accommodate growth without an unacceptable compromise of hull strength, reserve buoyance, or stability [95]. Service life allowances can again take the form of either a weight or KG margin. In essence, acquisition margins are incorporated to address short-term weight issues while service life allowances combat long-term weight and stability concerns. As such, the selection of a suitable service life allowance is the primary solution for the aforementioned conversion challenges resulting from weight buildup.

The selection of any margin must represent a balance between cost and risk. A non-existent or low margin can result in an exceedance of naval architectural or design limitations and therefore a lowered service life. A margin that is too conservative, however, may lead to irrevocable financial difficulties and an unnecessarily large ship size. With such implications, margin decisions can be inherent to a design's success. To aid in the decision-making process, various selection methods can be followed, including those outlined by the International Society of Allied Weight Engineers. For acquisition margins, the recommended practice is to use a risk-based selection process that considers the design's uncertainty and risk consequence. By referencing statistical data, mean recommended margins are suggested while a risk model such as the one shown in Figure 6.1 aids in the final margin selection.

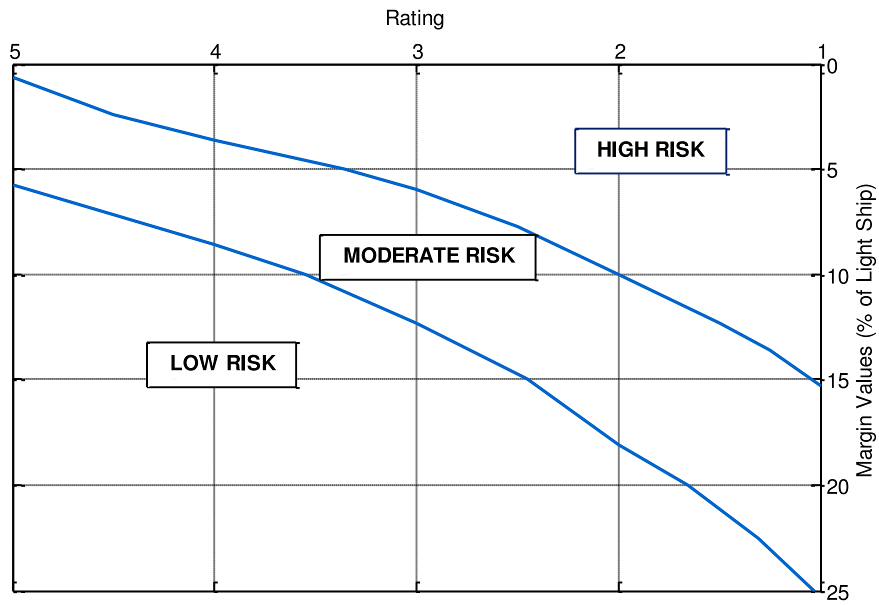

Figure 6.1. Risk-based weight margin selection

Source: based on [95]

Here, the rating represents a design's uncertainty level. A value of one represents a developmental design that is fundamentally different from reference vessels while a five is assigned to vessels that are of a follow-up or sister design. The intermediate ratings follow accordingly. By comparing the uncertainty with a selected margin, the project will fall into either a high, moderate, or low risk zone. A high-risk scenario may not meet safety limits or may require significant redesign, a moderate-risk situation can be controlled with effective weight control, and a low-risk design features little uncertainty. The goal is to lower the risk as much as feasibly possible when considering time, cost, and practical limitations. For cruise ships, shipyards use low margin levels due to the availability of prior statistics and low risk.

Appropriate service life allowance levels are more difficult to suggest. This is due in part to a lower level of available statistical data in comparison to the launching data used for the development of acquisition margin percentages. While the suggested practices devote much consideration to the risk-based model for acquisition margins, for instance, less than a page is allocated to service allowances. A simple range of suggested reserves is provided for weight and KG, though the reference ships are limited to naval vessels. With similar cruise ship data, as presented in Figure 3.4, similar ranges can be developed.

Fundamentally, an allowance should vary according to a ship's planned service life and expected weight growth. Therefore, the operator should provide input along with designers. It has been shown that the brand lives of modern cruise ships have increased in recent times, reaching 25 to 30 years (Table 3.1), though a vessel's service life can greatly exceed its brand life. This is compared to an approximated average weight gain of 3% over 10 years or 6% over 15 (Figure 3.4). Even with limited data, suggested allowances can be determined, assuming reference ships are comparable. Using this information, a suggested service life allowance in the range of 3% to 5% should be applied for cruise ships. This considers an initial 10 year period, after which more attention will be needed. Alternatively, the recommended practice could be given in terms of shorter phases, for instance 1% to 3% per five-year period, to yield a more customizable approach. A more conservative allowance is warranted for an operator that has a tendency to invest in significant conversions over a vessel's lifespan.

Though standard practices provide only simple allowance ranges like these, a more in-depth risk approach could be taken in a similar manner as with acquisition margins. Sister ships or derived designs will feature very low design rating risks, especially if enough time has passed to allow for a collection of weight measurements from the earlier vessels. In such cases, lower service life allowances may be warranted.

One final suggestion comes in the form of a proper weight control program. This type of program is the continuation of a successful initial weight estimation and margin selection, as it formally describes all weights from initial design to the end of a vessel's lifespan. Many components are involved, including weight estimation, reporting, and calculating [95]. The objective is to ensure a vessel's continued compliance with both regulations and naval architectural limits in order to continue safe operation without compromise. The level of detail needed decreases with increased service life allowances, though all allowances are slowly depleted during a ship's lifespan. As such, careful monitoring is crucial to identify potential stability issues at an early enough stage to allow for timely corrective planning.

The suggested initial design solutions to combat inevitable weight gain and potentially diminished stability are summarized below.

i. *Develop and closely follow a set weight and KG reserve principle for initial weight estimation. Choose appropriate margins based on standard industry practices.*

ii. *Focus especially on a vessel's service life allowance, giving an adequate reserve to compensate for both general buildup and conversion additions. Select an allowance based on past statistics, risk levels, past conversion trends, and planned service life.*

iii. *Implement a weight control program designed for a vessel's entire lifespan.*

6.4 Summary

Many initial design measures can be used to minimize the effects of the conversion challenges identified in Chapter 5. Acknowledged solutions take the form of both arrangement principles and allowances. Structural fire integrity concerns are addressed with conservative boundary designations. By selecting insulation that is compliant with both existing and probable conversion requirements and avoiding the designation of category 9 spaces, conversion tasks related to insulation upgrades will diminish. The aim of the means of escape recommendations is to reduce the need to widen an escape way or add new lifesaving crafts. This is accomplished through both margins and arrangement principles. The former is used for escape calculations while the latter focuses on the conservative designation of assembly stations. Finally, diminished stability concerns are downplayed in initial design by including appropriate acquisition margins and a service life allowance for weight and KG. Implementing a weight control plan can also help by allowing up-to-date specifications to be used in the decision-making process. Table 6.7 represents an outline of key design recommendations with respect to each case and discipline.

Table 6.7 Provident initial design summary

Conversion Case → / ↓ Discipline	Former space converted to multiple smaller spaces [CASE 1]	Multiple smaller spaces converged into single larger one [CASE 2]	Outer deck rebuilt with enclosed cabin or public spaces [CASE 3]	Heavy, concentrated additions [CASE 4]	Large public space designated as assembly station [additional consideration]
Structural Fire Protection	specify perimeter bulkheads to meet dual 3/8 space requirements when adjacent to public or service spaces	classify small public areas and cabins in probable conversion spaces as dual 7/8 when oriented near cat. 1, 8, and 11 spaces	specify deck insulation below forward and aft upper, open deck spaces in accordance with cat. 8 requirements in order to fulfill all cat. 3, 7, and 8 conversion possibilities	[-]	classify appropriate large public spaces as dual 8/4 spaces with regard to deck insulation underneath and bulkhead insulation
	specify deck above to meet dual 3/8 space requirements when below cat. 12 and deck below when above 11	classify all corridors within probable conversion spaces as dual 3/8 spaces			specify conservative floor covering materials in accordance with FTP code requirements
Means of Escape and Evacuation	design conservative evacuation plan and escape calculations, particularly for night condition and especially in upper decks	design conservative evacuation plan and escape calculations, particularly for day condition and especially in upper decks	include open decks in preliminary escape calculations as a conservative measure, even though regulations do not stipulate inclusion	[-]	design all large, non-adjacent public spaces near evacuation stations in accordance with assembly station requirements with regard to means of escape
	include a margin for total number of persons onboard in order to allocate a buffer for added cabins and passengers				
Stability	include an appropriate service life allowance in preparation for the added weights implied with converting a public space to a cabin area, along with many other weight additions	[-]	[-]	include initial lightweight margins in addition to an appropriate service life allowance and weight control program to combat general weight increases and future conversion additions	[-]

7 Case study

The principles and recommendations outlined in the preceding chapters are now used as the foundation for a case study. The aim is to illustrate chosen methods and identify the prevalence and impact of the various conversion cases by considering a new cruise ship. The chosen vessel, *Celebrity Reflection*, meets the scope requirements as a modern ship aimed at the U.S. market. Built in 2012, it also features current design trends. The case study focuses on structural fire protection, since it is the most tangible of the three disciplines. Means of escape is also taken into account with regard to a single space. Stability is not considered since its recommendations consist solely of margins. The methodology and results are divided by discipline and the chapter concludes with a discussion of the study's general implications.

7.1 Structural fire protection

For structural fire protection, a sample general arrangement of *Celebrity Reflection* is used to highlight the fire integrity recommendations to be considered in initial design. Each deck featuring probable conversion spaces are detailed and presented in Appendix F. There are two main goals when considering this discipline. The first is to identify the probable conversion areas on the ship, or those that meet the criteria for one of the three conversion cases. This is shown with thick boundary lines corresponding to each case. For case one, large public spaces, the rooms on the upper decks and at the fore and aft ends of the ship are a focus, along with secondary or redundant spaces on the lower public decks. These are marked with a blue border. Smaller spaces are enclosed in a yellow boundary when located in an area that could easily be converted into a larger public space. Finally, selected open deck spaces on the upper decks are marked with a green boundary.

Once the probable areas are marked, their orientations are studied with respect to Table A 18. It is necessary to consider the spaces and categories above, below, and beside the space in question. Boundaries that require reinforcement, assuming the identified conversion case is carried out, are marked with red hatches and lines. For decks, a diagonal line hatch represents insulation that requires upgrading due to the influence of the space category being considered. A crosshatch represents insulation that requires upgrading due to the space category on the deck above.

For each probable conversion area, the previously identified limiting category is compared to the current one. For the first conversion case, this is category 3 and for the third case, category 8 is chosen. The more conservative between category 7 and category 3 is selected for the second conversion case. Each boundary that could require an upgrade is marked with a table of insulation classes. The first row in each table represents the existing scenario and corresponding boundary requirement while the second shows the SOLAS requirement for the selected conversion case. There is also a third row, which considers the conversion of both the existing space and the space above, assuming both lie within a conversion boundary. Figure 7.1 is an extract from Appendix F, showing the forward section of deck 14. It illustrates two of the conversion boundaries, potential deck and bulkhead upgrade situations, and integrity tables for each scenario.

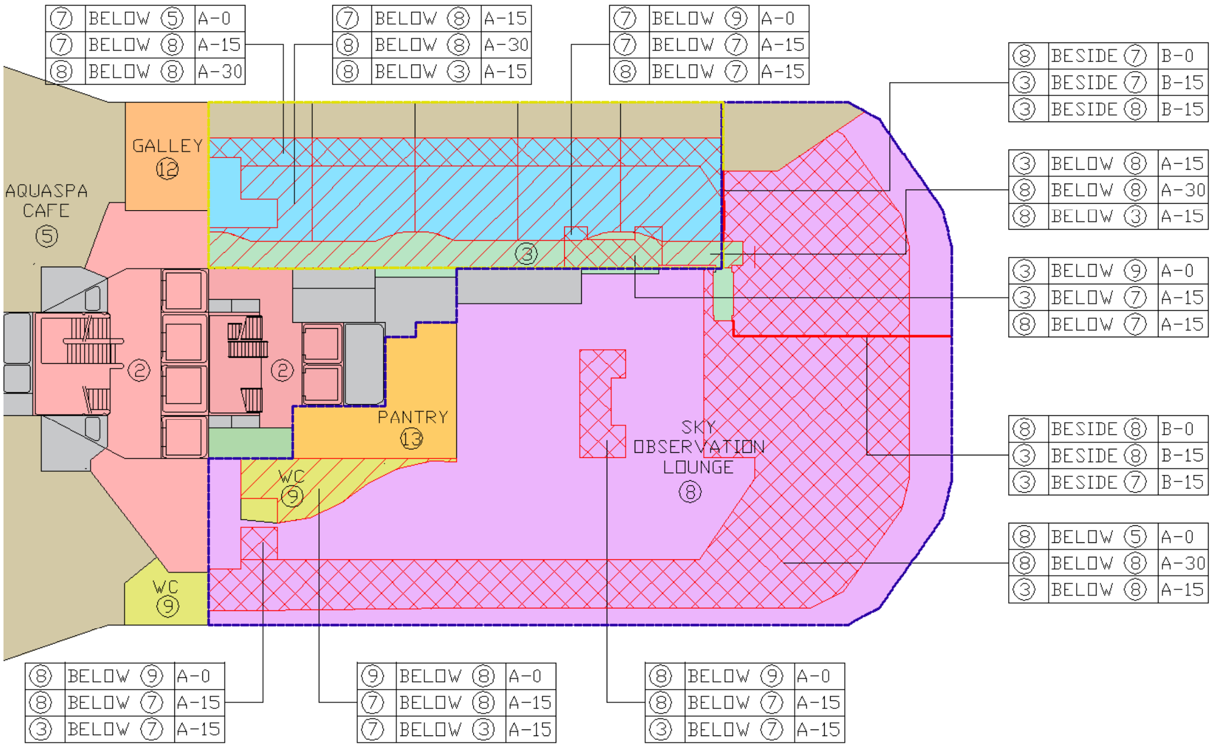

Figure 7.1. Appendix F excerpt, *Celebrity Reflection*

This sample, along with the Appendix F drawings, illustrates a potential approach for a provident initial design. If completed during the detail design phases, appropriate materials can be selected in order to ensure a convenient conversion in the future. Here, the idea is to select the most conservative integrity class from each table, at least for the areas deemed most likely to undergo restructuring. Doing so will cover all bases for future conversions without needing a detailed conversion plan at the beginning of a ship's lifecycle.

7.2 Means of escape and evacuation

Unlike the first discipline, it is not feasible to consider the entire sample ship with respect to the identified means of escape and evacuation recommendations. While a holistic look at the minimum required escape ways, lifesaving capacities, and assembly stations would illustrate the advantages of the proposed approach, their calculation would require detailed vessel information. Parameters such as the number of seats per public space, allocation of crew by public, service, and accommodation space, and assembly station designation are not known and therefore a generalized outcome cannot be attained. With certain assumptions, however, a single space can be considered in order to exemplify key initial design considerations.

The goal of this portion of the study is to demonstrate the importance of initial escape margins. To do this, the same deck 14 area is taken into account because of its high conversion probability. Figure 7.2 shows this area, with the original design on the left and two potential conversion scenarios on the right. The first is a case where six former cabins are removed in order to enlarge the lounge while more cabins are added in the second case in a manner similar to those shown in Appendix D.

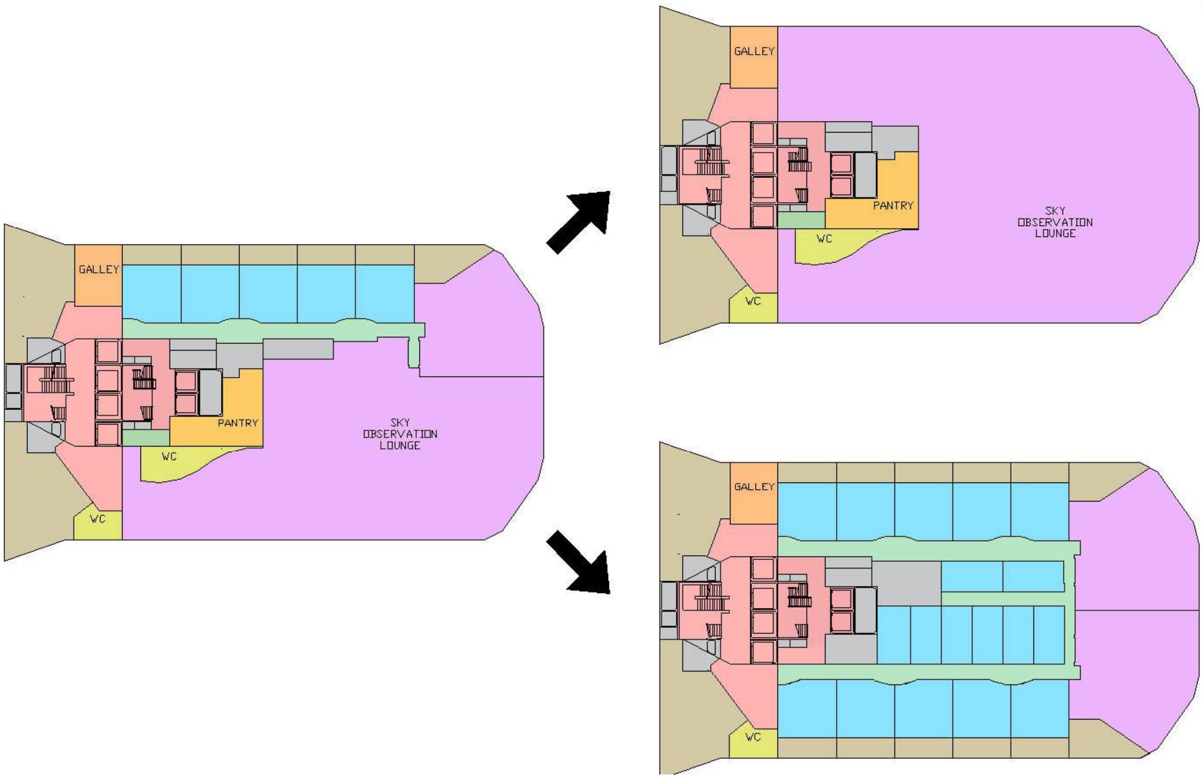

Figure 7.2. Probable conversion scenarios, *Celebrity Reflection*

By using this space, two common conversion cases are considered. Additionally, since cabins and a public room are present, the effect of both the day and night calculations are shown. For each of the three arrangements, approximate minimum stair widths are calculated by following the procedure outlined in Chapter 5.2.1.1. The results are provided in Table 7.1, Table 7.2, and Table 7.3. Since some information is unavailable and dimensioning is only estimated based on the sample general arrangement, calculations are representative only.

Various assumptions are made in order to perform the estimations. For cabins, the maximum capacity is taken as four persons as a conservative measure. The capacities of the category 8 public spaces are estimated with the $2m^2$ area per person figure from SOLAS. Crew capacities are roughly estimated based on the number of passengers occupying the space. Public spaces in the night condition always feature half of the crew as the day since 2/3 of the total crew should be allocated during the day and only 1/3 at night. The same is true for service spaces, which include cabin areas in this situation. In the second example, cabins are dimensioned according to existing ones, since cabin uniformity is normally desired. Finally, a landing credit allowance is applied in each case. While adequate for this type of estimation, these assumptions likely yield more conservative minimum dimensions than exist, as the designed public space capacities are likely much lower.

Calculations are completed for deck 14 and the deck above, as minimum stair widths are dependent on four decks. Deck 16 is not considered since it consists only of open deck space, though including its conversion scenario would yield even greater implications. As it stands, the results are as expected, with the increased public space in the first scenario demanding a widened staircase for the daytime condition and an increased nighttime dimension due to the new cabins in the second case. Overall, the first scenario proves to be critical, as it would necessitate the widening of at least the current deck's staircase, if not those below as well.

Again, this methodology can be used in initial design to reduce the chance of such a widening. Even more scenarios can be considered as well, including one where smaller cabins are added instead of suites. This could increase the nighttime load by a factor of two or more, which would in turn increase the calculated minimum width. Ultimately, the considered scenarios should be introduced at the discretion of the operator and designers, based on what they view as the most probable.

Table 7.1 Existing arrangement

DECK ABOVE CALCULATION			
Deck 15 public space area		570	m2
Deck 15 maximum passengers		285	persons
Deck 15 maximum crew		25	persons
DECK 14 AREAS			
Observation Lounge		750	m2
Cabins		[-]	m2
ESTIMATED MAXIMUM PERSONS			
		Pax.	Crew
Observation Lounge		375	25
Cabins		24	2
Total		399	27
DAY CONDITION CALCULATION			
Escaping Persons			
	Pax.	Crew	Total
Observation Lounge	375	25	400
Cabins	0	2	2
Total	375	27	**402**
Minimum dimensions			
Landing credit?		YES	
Escaping persons D15		310	persons
LCA application		233	persons
Dimension		2330	mm
Escaping persons D14		402	persons
LCA application		302	persons
Dimension		3015	mm
Required dimension		**5345**	**mm**
NIGHT CONDITION CALCULATION			
Escaping Persons			
	Pax.	Crew	Total
Observation Lounge	0	0	0
Cabins	24	1	25
Total	24	1	**25**
Minimum dimensions			
Landing credit?		YES	
Escaping persons D15		0	persons
LCA application		0	persons
Dimension		0	mm
Escaping persons D14		25	persons
LCA application		19	persons
Dimension		190	mm
Calculated dimension		**190**	**mm**
Required minimum		**5345**	**mm**

Table 7.2 Example 1 arrangement

DECK ABOVE CALCULATION			
Deck 15 public space area		570	m2
Deck 15 maximum passengers		285	persons
Deck 15 maximum crew		25	persons
DECK 14 AREAS			
Observation Lounge		1300	m2
Cabins		[-]	m2
ESTIMATED MAXIMUM PERSONS			
		Pax.	Crew
Observation Lounge		650	40
Cabins		0	0
Total		650	40
DAY CONDITION CALCULATION			
Escaping Persons			
	Pax.	Crew	Total
Observation Lounge	650	40	690
Cabins	0	0	0
Total	650	40	**690**
Minimum dimensions			
Landing credit?		YES	
Escaping persons D15		310	persons
LCA application		233	persons
Dimension		2330	mm
Escaping persons D14		690	persons
LCA application		518	persons
Dimension		5175	mm
Required dimension		**7505**	**mm**
NIGHT CONDITION CALCULATION			
Escaping Persons			
	Pax.	Crew	Total
Observation Lounge	0	0	0
Cabins	0	0	0
Total	0	0	**0**
Minimum dimensions			
Landing credit?		YES	
Escaping persons D15		0	persons
LCA application		0	persons
Dimension		0	mm
Escaping persons D14		0	persons
LCA application		0	persons
Dimension		0	mm
Calculated dimension		**0**	**mm**
Required minimum		**7505**	**mm**

Table 7.3 Example 2 arrangement

DECK ABOVE CALCULATION			
Deck 15 public space area		570	m2
Deck 15 maximum passengers		285	persons
Deck 15 maximum crew		25	persons
DECK 14 AREAS			
Observation Lounge		0	m2
Cabins		[-]	m2
ESTIMATED MAXIMUM PERSONS			
		Pax.	Crew
Observation Lounge		0	0
Cabins		80	4
Total		80	4
DAY CONDITION CALCULATION			
Escaping Persons			
	Pax.	Crew	Total
Observation Lounge	0	0	0
Cabins	0	4	4
Total	0	4	**4**
Minimum dimensions			
Landing credit?		YES	
Escaping persons D15		310	persons
LCA application		233	persons
Dimension		2330	mm
Escaping persons D14		4	persons
LCA application		3	persons
Dimension		30	mm
Required dimension		**2360**	**mm**
NIGHT CONDITION CALCULATION			
Escaping Persons			
	Pax.	Crew	Total
Observation Lounge	0	0	0
Cabins	80	2	82
Total	80	2	**82**
Minimum dimensions			
Landing credit?		YES	
Escaping persons D15		0	persons
LCA application		0	persons
Dimension		0	mm
Escaping persons D14		82	persons
LCA application		62	persons
Dimension		620	mm
Calculated dimension		**620**	**mm**
Required minimum		**2360**	**mm**

7.3 Case study outcomes

The primary goal of the case study was to illustrate potential methods that can be used for the outlined provident design approach. This has been done for fire protection and escape by using the *Celebrity Reflection* as an example. From this, the major takeaway is that the initial design recommendations are easily implemented for each discipline. The study also yields additional outcomes, however, by illustrating the prevalence and impact of each case. This allows for a deeper understanding of the design proposals from Chapter 6.

For the public space conversion case, most identified potential insulation changes concern bulkheads. The only deck modifications are related to isolated spaces such as categories 9, 12, and 13. While category 8 spaces are the most common, category 9 and 13 spaces also necessitated upgraded bulkhead insulation. This supports the recommendation to consider category 9 and 13 pantries in initial design. With respect to escape, the calculations show the influence of the conversion on the nighttime condition.

Small area conversion cases are less common. In those identified, the deck insulation is more demanding, as bulkheads are generally removed. The spaces identified here include spa and upper cabin spaces, where category 3 and 7 spaces were taken into consideration. Usually, modifications are needed when above or below a category 8 space. The effect on daytime stair width calculations is also shown, with the example given representing a case where widened dimensions could be necessitated. For the open deck case, decks are again critical and the changes are often more severe. The occurrence of such areas, however, is more concentrated. Specifying an A-30 insulation is suitable for all scenarios unless a galley is below the open deck in question.

Overall, the study shows the importance of certain space categories and depicts the potential scope of the initial design recommendations. Though numerous changes are given, they are limited with respect to the vessel as a whole and both the fire and escape examples represent modifications that are simple to implement in initial design but much more difficult in conversion engineering.

8 Discussion and conclusion

The main research question and three sub-questions have been answered. By identifying the major drivers, tasks, and cases in today's conversion projects, following a rules-based approach to identify design implications, and identifying areas for improvement with respect to three disciplines, succinct initial design recommendations have be outlined.

An extensive background and conversion trend study was completed as an integral foundation for later design implications and recommendations. By first reviewing the industry challenges that stimulate today's conversion drivers and later identifying the drivers themselves, a deeper understanding of the conversion tasks, cases, and developed solutions is garnered. This context, along with the regulations from which initial design implications are extracted, facilitates a rounded approach to fulfilling the thesis aims through both expansive and narrow focuses. Once solutions were outlined and the research questions answered, a case study was developed as a means to illustrate potential initial design methodology and the severity of the conversion cases considered. Though the proposed recommendations are as specific and direct as possible, proving their effectiveness is difficult with respect to available resources. Various additional considerations could also be taken into account to improve the study through future iterative progressions. These issues are discussed in this chapter.

8.1 Overview of research outcomes

A general aim of the thesis was to contribute to the fields of cruise ship conversions and farsighted ship design. This has been realized through background research, statistical analysis, literary and regulatory reviews, and a case study. More specifically, three sub-research questions and one overarching question were presented and each has been answered. In order to summarize the final thesis outcomes, each question is revisited below.

"What are the major drivers and tasks in today's conversion projects?"

Key conversion drivers and tasks are outlined in Chapter 3 and Chapter 4.1. The drivers, or justifications for a project, are generally either technical or strategic in nature. Technical drivers are usually mandatory considerations, as they are stipulated by governing bodies or have effects on the operational success of a ship. These include a vessel's age, environmental impact, operational redundancy and efficiency, and stability. Strategic drivers differ since they are implemented at the discretion of the operator in order to gain a competitive edge.

Revenue, fleet standardization, deployment, and market competition represent strategic concerns that directly affect conversion plans.

"What regulations must be followed and what technical solutions are needed to complete the conversion tasks?"

Many rules and regulations govern the design and operation of cruise ships. Chapter 3.1.2 covers those that are especially relevant in conversion engineering while Chapter 5 narrows the focus to key requirements. Emphasis is placed on SOLAS and its congruent publications and stipulations are outlined with respect to the three selected naval architectural disciplines: structural fire protection, means of escape and evacuation, and stability. The necessary regulatory requirements give insight into the methods used to complete the identified tasks.

"Could the completed changes have been avoided or simplified through better planning at the initial design stage?"

Both regulatory stipulations and their impact on conversions are discussed in Chapter 5. The outlined impacts describe the challenges of completing each task with respect to each discipline. The solutions to each challenge are time consuming in both the conversion planning and execution stages. Specific challenges include reinforcement of integrity boundaries, widening of escape ways, redesign of assembly stations and evacuation procedures, and the addition of sponson-ducktails. Each of these can potentially be avoided with a better initial design methodology.

"What can be done at the initial design stage to minimize conversion planning, length, and costs in the future?"

The primary outcome is that there are many provident initial design measures that can help improve conversion processes in the future. Recommendations for each of the three disciplines are discussed in Chapter 6 while a broad outline is presented in Table 6.7. The majority of the recommendations are simple with minimal cost concerns at the initial design and acquisition stages. To minimize fire integrity challenges, conservative classification of specific boundaries can be adopted. Both arrangement principles and allowances can be helpful in reducing the effects of escape and evacuation challenges, including conservative evacuation calculations and escape way and occupancy margins. Finally, stability concerns can be diminished with integrated margins and service life allowances.

8.2 Effectiveness of recommendations

The degree to which the outlined recommendations may simplify conversions is difficult to explicate. Primarily, this is due to a lack of specific conversion data, especially concerning costs. The overall costs of these projects are sometimes referenced and estimations for major components, such as sponson-ducktails, may be estimated. Still, a more detailed breakdown is needed to ascertain the potential degree of improvement. The cost of replacing boundary insulation, for instance, is a specific parameter that would allow for detailed savings estimations. The same is true for worker distributions, as the time and resources allocated to various tasks could be compared to the total off-hire time and monetary losses experienced as a result. As it stands, such considerations are beyond the scope of the thesis and results must be generalized based on the studied reference vessels.

To conclude, the reference conversion tasks listed in Appendix B are again visited. Now, the aim is to determine which tasks may have been avoided or at least simplified had the proposed outline been followed during initial design. Appendix G provides corresponding new tables showing each task, its assumed conversion challenge, and a prediction as to whether the outlined recommendations would have helped. Again, this cannot be stated with certainty without a detailed list of completed conversion work, but the before and after specifications, along with SOLAS, give enough background to make such assumptions.

For all cases, the outline focuses on major conversion tasks rather than simpler refurbishments. Accordingly, the proposals will have greater effect on larger conversions and this can be seen by comparing the tasks between the three reference ships. Only six of the tasks for *Brilliance of the Seas* are predicted as being affected by the provident approach, with the remaining eleven representing tasks with minimal inherent challenges. This is compared with fifteen tasks for *Carnival Sunshine*, which underwent a more comprehensive conversion.

It can be assumed that the tasks affected by the outline are time consuming and costly, especially when compared to refurbishments. As such, minimizing the time and resources for such tasks would be beneficial for the operator. More specifically, reducing the need to upgrade boundary insulation and bypassing the need for a sponson-ducktail would directly reduce the time needed for the conversion drydock and planning of projects such as these. While the need to increase escape widths is not identified for these references, it is safe to assume that considerations regarding escape and evacuation were taken into account. This is especially true for the *Sunshine* due to the vast increase in passenger capacity. The recommendations related to this discipline should therefore be valid as well.

8.3 Future considerations

A narrow scope is essential for a manageable thesis. Broadening the scope, however, would naturally produce more generalized results. Even though the proposed research question has been answered, there is opportunity for further investigation. Concerning the defined scope, this thesis focuses solely on large, contemporary cruise ships aimed at the U.S. market and the proposed recommendations cannot be applied to other segments without further research. A study into premium and luxury conversions, or conversions aimed at specific nationalities, could result in slightly different or expanded recommendations. Further expansion is also possible by studying the trends, challenges, and solutions of crew and service spaces.

Even for the scope chosen, future iterations would allow for the development of more ideas. In this work, four main conversion cases and three naval architectural disciplines are taken into account. Expanding either of these would be beneficial and allow for a more rounded design approach. Additional cases could include detailed scenarios, such as the conversion of suites into smaller cabins or the opposite, or the modification of a former public space into a restaurant. The same is true for the selected disciplines. In addition to fire, escape, and stability concerns, others also have large effects on conversions. HVAC and electrical modifications are two examples that demand extensive time and resources in conversion engineering and identifying solutions for these would enhance the provident design approach. Finally, with more data, a comprehensive study into the impact of each proposed solution can be evaluated. Such information would be needed in order to prove that such initial design investments would reap measurable benefits. Reporting detailed estimations on expected savings would likely be needed for an operator to agree to such an approach.

8.4 Closing remarks

Even with the future implications, the results show promising potential for a farsighted initial design approach with respect to conversion engineering. The recommendations are aimed primarily at vessel operators, as they would benefit the most from the savings. Shipyards, for instance, would profit less, as they seek contracts and therefore need to keep project costs at a minimum. This likely spurs minimal use of provident measures including design margins.

Even so, the simplified conversion processes for the shipyard and monetary savings for the operator could together make such a design approach more desirable.

Regarding the methodology used throughout the thesis, a rules-based approach was followed in order to develop the final outline. One risk of such an approach is that rules evolve over time. Many current SOLAS rules regarding fire protection and escape were introduced in the early 1990s, for instance, meaning older vessels are subject to earlier adaptations. As such, some parameters, such as specific integrity class requirements, may be invalid in the distant future. The procedures used to identify the solutions can easily be adapted, however, regardless of the specifics of SOLAS or other regulations, as the general form of the regulations are consistent.

The process of completing this work has been both challenging and rewarding. The past six months have been exiting for the cruise industry, with many developments for most major cruise lines. Numerous newbuild and rebranding announcements have recently been released and the growth of the industry again looks promising. The industry's short history has illustrated its unpredictability, however, and it is safe to assume that conversions will continue to play a significant role in its future development. Designing a ship to be as 'convertible' as possible will therefore be a relevant approach as the industry evolves.

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10 List of appendices

Appendix A – Major cruise line fleet age database

Table A 1. Carnival Cruise Line fleet age data

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Average Age by Year
Mardi Gras	Carnivale	Festivale	Tropicale	Holiday	Jubilee	Celebration	Carnival Fantasy	Carnival Ecstasy	Carnival Sensation	Carnival Fascination	Carnival Imagination	Carnival Inspiration	Carnival Destiny*	Carnival Elation	Carnival Paradise	Carnival Triumph	Carnival Victory	Carnival Spirit	Carnival Pride	Carnival Legend	Carnival Conquest	Carnival Glory	Carnival Miracle	Carnival Valor	Carnival Liberty	Carnival Freedom	Carnival Splendor	Carnival Dream	Carnival Magic	Carnival Breeze	Project Vista	
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																																[-]
a																																[-]
11																																11.0
12																																12.0
13	a																															13.0
14	19																															16.5
15	20	a																														17.5
16	21	15																														17.3
17	22	16																														18.3
18	23	17																														19.3
19	24	18																														20.3
20	25	19																														21.3
21	26	20	0																													16.8
22	27	21	1																													17.8
23	28	22	2																													18.8
24	29	23	3	0																												15.8
25	30	24	4	1	0																											14.0
26	31	25	5	2	1	0																										12.9
27	32	26	6	3	2	1																										13.9
28	33	27	7	4	3	2																										14.9
29	34	28	8	5	4	3	0																									13.9
30	35	29	9	6	5	4	1	0																								13.2
31	36	30	10	7	6	5	2	1																								14.2
32	37	31	11	8	7	6	3	2	0																							13.7
x	38	32	12	9	8	7	4	3	1	0																						11.4
	x	33	13	10	9	8	5	4	2	1	0																					8.5
		34	14	11	10	9	6	5	3	2	1	0	0																			7.9
		x	15	12	11	10	7	6	4	3	2	1	1																			6.5
			16	13	12	11	8	7	5	4	3	2	2	0	0																	6.4
			17	14	13	12	9	8	6	5	4	3	3	1	1	0																6.9
			18	15	14	13	10	9	7	6	5	4	4	2	2	1	0															7.3
			19	16	15	14	11	10	8	7	6	5	5	3	3	2	1	0	0													7.4
			x	17	16	15	12	11	9	8	7	6	6	4	4	3	2	1	1	0	0											6.8
				18	17	16	13	12	10	9	8	7	7	5	5	4	3	2	2	1	1	0										7.4
				19	18	17	14	13	11	10	9	8	8	6	6	5	4	3	3	2	2	1	0	0								7.6
				20	x	18	15	14	12	11	10	9	9	7	7	6	5	4	4	3	3	2	1	1	0							7.7
				21		19	16	15	13	12	11	10	10	8	8	7	6	5	5	4	4	3	2	2	1							8.7
				22		20	17	16	14	13	12	11	11	9	9	8	7	6	6	5	5	4	3	3	2	0						9.2
				23		21	18	17	15	14	13	12	12	10	10	9	8	7	7	6	6	5	4	4	3	1	0					9.8
				24		x	19	18	16	15	14	13	13	11	11	10	9	8	8	7	7	6	5	5	4	2	1	0				9.8
				x			20	19	17	16	15	14	14	12	12	11	10	9	9	8	8	7	6	6	5	3	2	1				10.2
							21	20	18	17	16	15	15	13	13	12	11	10	10	9	9	8	7	7	6	4	3	2	0			10.7
							22	21	19	18	17	16	16	14	14	13	12	11	11	10	10	9	8	8	7	5	4	3	1	0		11.2
							23	22	20	19	18	17	17	15	15	14	13	12	12	11	11	10	9	9	8	6	5	4	2	1		12.2
							24	23	21	20	19	18	18	16	16	15	14	13	13	12	12	11	10	10	9	7	6	5	3	2		13.2
							25	24	22	21	20	19	19	17	17	16	15	14	14	13	13	12	11	11	10	8	7	6	4	3		14.2
							26	25	23	22	21	20	20	18	18	17	16	15	15	14	14	13	12	12	11	9	8	7	5	4	0	14.6

Table A 2. Royal Caribbean International fleet age data

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	Average Age by Year
Song of Norway	Nordic Prince	Sun Viking	Song of America	Sovereign of the Seas	Viking Serenade	Nordic Empress	Monarch of the Seas	Majesty of the Seas	Legend of the Seas	Splendour of the Seas	Grandeur of the Seas	Rhapsody of the Seas	Enchantment of the Seas	Vision of the Seas	Voyager of the Seas	Explorer of the Seas	Radiance fo the Seas	Adventure of the Seas	Brilliance of the Seas	Navigator of the Seas	Serenade of the Seas	Mariner of the Seas	Jewel of the Seas	Freedom of the Seas	Liberty of the Seas	Independence of the Seas	Oasis of the Seas	Allure of the Seas	Quantum of the Seas	Anthem of the Seas	Project Oasis 3	Project Quantum 3	
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																																	[-]
																																	[-]
																																	[-]
																																	[-]
0																																	0.0
1	0																																0.5
2	1	0																															1.0
3	2	1																															2.0
4	3	2																															3.0
5	4	3																															4.0
6	5	4																															5.0
7	6	5																															6.0
8	7	6																															7.0
9	8	7																															8.0
10	9	8																															9.0
11	10	9																															10.0
12	11	10	0																														8.3
13	12	11	1																														9.3
14	13	12	2																														10.3
15	14	13	3																														11.3
16	15	14	4																														12.3
17	16	15	5																														13.3
18	17	16	6	0																													11.4
19	18	17	7	1	a																												12.4
20	19	18	8	2	8	0																											10.7
21	20	19	9	3	9	1	0																										10.3
22	21	20	10	4	10	2	1	0																									10.0
23	22	21	11	5	11	3	2	1																									11.0
24	23	22	12	6	12	4	3	2																									12.0
25	24	23	13	7	13	5	4	3	0																								11.7
26	x	24	14	8	14	6	5	4	1	0	0																						9.3
27		25	15	9	15	7	6	5	2	1	1	0	0																				8.7
x		26	16	10	16	8	7	6	3	2	2	1	1	0																			7.5
		x	17	11	17	9	8	7	4	3	3	2	2	1	0																		6.5
			x	12	18	10	9	8	5	4	4	3	3	2	1	0																	6.1
				13	19	11	10	9	6	5	5	4	4	3	2	1	0	0															6.1
				14	20	12	11	10	7	6	6	5	5	4	3	2	1	1	0	0													6.3
				15	x	13	12	11	8	7	7	6	6	5	4	3	2	2	1	1	0	0											5.7
				16		14	13	12	9	8	8	7	7	6	5	4	3	3	2	2	1	1	0										6.4
				17		15	14	13	10	9	9	8	8	7	6	5	4	4	3	3	2	2	1										7.4
				18		16	15	14	11	10	10	9	9	8	7	6	5	5	4	4	3	3	2	0									8.0
				19		17	16	15	12	11	11	10	10	9	8	7	6	6	5	5	4	4	3	1	0								8.5
				20		18	17	16	13	12	12	11	11	10	9	8	7	7	6	6	5	5	4	2	1	0							9.1
				x		x	18	17	14	13	13	12	12	11	10	9	8	8	7	7	6	6	5	3	2	1	0						8.7
							19	18	15	14	14	13	13	12	11	10	9	9	8	8	7	7	6	4	3	2	1	0					9.2
							20	19	16	15	15	14	14	13	12	11	10	10	9	9	8	8	7	5	4	3	2	1					10.2
							21	20	17	16	16	15	15	14	13	12	11	11	10	10	9	9	8	6	5	4	3	2					11.2
							22	21	18	17	17	16	16	15	14	13	12	12	11	11	10	10	9	7	6	5	4	3					12.2
							x	22	19	18	18	17	17	16	15	14	13	13	12	12	11	11	10	8	7	6	5	4	0				12.2
								23	20	19	19	18	18	17	16	15	14	14	13	13	12	12	11	9	8	7	6	5	1	0			12.6
								24	21	20	20	19	19	18	17	16	15	15	14	14	13	13	12	10	9	8	7	6	2	1	0	0	12.5

Table A 3. Princess Cruises fleet age data

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	Average Age by Year
Princess Patricia	Princess Italia	Princess Carla	Island Princess	Sun Princess	Pacific Princess	Royal Princess	Sea Princess	Fair Princess	Dawn Princess	Sky Princess	Star Princess	Crown Princess	Regal Princess	Golden Princess	Sun Princess	Dawn Princess II	Sea Princess II	Grand Princess	Ocean Princess	Golden Princess II	Star Princess II	Coral Princess	Ocean Princess II	Pacific Princess II	Island Princess II	Diamond Princess	Caribbean Princess	Sapphire Princess	Crown Princess II	Emerald Princess	Royal Princess II	Ruby Princess	Royal Princess III	Regal Princess II	
e																																			[-]
17	a																																		17.0
18	2	a																																	10.0
x	3	16																																	9.5
	4	17																																	10.5
	5	18																																	11.5
	6	x																																	6.0
	7																																		7.0
	8		a	a																															8.0
	9		3	2	a																														4.7
	x		4	3	4																														3.7
			5	4	5																														4.7
			6	5	6																														5.7
			7	6	7																														6.7
			8	7	8																														7.7
			9	8	9																														8.7
			10	9	10																														9.7
			11	10	11																														10.7
			12	11	12																														11.7
			13	12	13	0																													9.5
			14	13	14	1	a																												10.5
			15	14	15	2	20																												13.2
			16	15	16	3	21	a	a	a																									14.2
			17	16	17	4	22	32	31	4																									17.9
			18	x	18	5	23	33	32	5	0																								16.8
			19		19	6	24	34	33	6	1	0																							15.8
			20		20	7	25	35	34	7	2	1	0																						15.1
			21		21	8	26	36	35	8	3	2	1	a																					16.1
			22		22	9	27	37	36	9	4	3	2	20																					17.4
			23		23	10	28	38	x	10	5	4	3	21																					16.5
			24		24	11	29	39		11	6	5	4	22	0																				15.9
			25		25	12	x	40		12	7	6	5	23	1																				15.6
			26		26	13		41		13	8	7	6	x	2	0																			14.2
			27		27	14		x		14	x	8	7		3	1	0	0																	10.1
			28		28	15				15		9	8		4	2	1	1																	11.1
			x		29	16				16		10	9		5	3	2	2	0																9.2
					30	17				17		11	10		6	4	3	3	1	0			a												9.3
					31	18				x		12	11		7	5	4	4	2	1	0	0	3	a											7.5
					x	19						x	12		8	6	5	5	x	2	1	1	4	4	0										5.6
						20							13		9	7	6	6		3	2	2	5	5	1	0	0	0							5.3
						21							14		10	8	7	7		4	3	3	6	6	2	1	1	1							6.3
						x							15		11	9	8	8		5	4	4	7	7	3	2	2	2	0		a				5.8
													16		12	10	9	9		6	5	5	8	8	4	3	3	3	1	0	6				6.4
													x		13	11	10	10		7	6	6	9	9	5	4	4	4	2	1	7	0			6.4
															14	12	11	11		8	7	7	10	10	6	5	5	5	3	2	8	1			7.4
															15	13	12	12		9	8	8	11	11	7	6	6	6	4	3	9	2			8.4
															16	14	13	13		10	9	9	12	12	8	7	7	7	5	4	10	3			9.4
															17	15	14	14		11	10	10	13	13	9	8	8	8	6	5	x	4			10.3
															18	16	15	15		12	11	11	14	14	10	9	9	9	7	6		5	0		10.6
															19	17	16	16		13	12	12	15	15	11	10	10	10	8	7		6	1	0	11.0
															20	18	17	17		14	13	13	16	16	12	11	11	11	9	8		7	2	1	12.0
															21	19	18	18		15	14	14	17	17	13	12	12	12	10	9		8	3	2	13.0

Table A 4. Costa Crociere fleet age data

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
Anna C	Andrea C	Franca C	Federico C	Bianca C	Enrico Costa	Eugenio Costa	Carla Costa	Flavia	Italia	Daphne	Danae	Amerikanis	Columbus C	Costa Riviera	Costa marina	Costa Classica	Costa Allegra	Costa Romantica*	Costa Playa	Costa Victoria	Costa Atlantica	Costa Tropicale	Costa Europa	Costa Mediterranea	Costa Fortuna	Costa Magica	Costa Concordia	Costa Serena	Costa Luminosa	Costa Pacifica	Costa Deliziosa	Costa Favolosa	Costa Voyager	Costa Fascinosa	Costa neoRiviera	Costa Diadema	Average Age over Time
e	e	e	e		a																																[-]
37	25	18	10		15	0																															17.5
38	26	19	11		16	1	a	a																													18.5
39	27	20	12		17	2	17	22																													19.5
40	28	21	13		18	3	18	23																													20.5
41	29	22	14		19	4	19	24																													21.5
42	30	23	15		20	5	20	25																													22.5
x	31	24	16		21	6	21	26	a																												20.7
	32	25	17		22	7	22	27	6																												19.8
	33	26	18		23	8	23	28	7																												20.8
	34	27	19		24	9	24	29	8																												21.8
	35	28	20		25	10	25	30	9																												22.8
	36	29	21		26	11	26	31	10																												23.8
	37	x	22		27	12	27	32	11	a	a																										24.0
	38		23		28	13	28	33	12	24	24	a																									24.8
	39		24		29	14	29	34	13	25	25	28	a																								26.0
	40		25		30	15	30	35	14	26	26	29	29																								27.2
	41		26		31	16	31	36	15	27	27	30	30	a																							28.2
	x		27		32	17	32	x	16	28	28	31	31	22																							26.4
			x		33	18	33		x	29	29	32	32	23																							28.6
					34	x	34			30	30	x	x	24																							30.4
					35		35			31	31			25																							31.4
					36		36			32	32			26																							32.4
					37		37			33	33			27																							33.4
					38		38			34	34			28																							34.4
					39		39			35	35			29	0																						29.5
					40		40			36	36			30	1	0																					26.1
					41		41			37	37			31	2	1	0																				23.8
					42		x			38	x			32	3	2	1	0																			16.9
					43					39				33	4	3	2	1	a																		17.9
					x					40				34	5	4	3	2	28																		16.6
										41				35	6	5	4	3	29	0																	15.4
										42				36	7	6	5	4	30	1																	16.4
										x				37	8	7	6	5	31	2																	13.7
														38	9	8	7	6	x	3		a															11.8
														39	10	9	8	7		4	0	18															11.9
														40	11	10	9	8		5	1	19	a														12.9
														41	12	11	10	9		6	2	20	16														14.1
														x	13	12	11	10		7	3	21	17	0	0												9.4
															14	13	12	11		8	4	22	18	1	1	0											9.5
															15	14	13	12		9	5	23	19	2	2	1											10.5
															16	15	14	13		10	6	x	20	3	3	2	0										9.3
															17	16	15	14		11	7		21	4	4	3	1	0									9.4
															18	17	16	15		12	8		22	5	5	4	2	1	0	0							8.9
															19	18	17	16		13	9		23	6	6	5	3	2	1	1							9.9
															20	19	18	17		14	10		24	7	7	6	4	3	2	2	0		a				10.2
															21	20	19	18		15	11		x	8	8	7	5	4	3	3	1	0	12				9.7
															x	21	20	19		16	12			9	9	8	6	5	4	4	2	1	13	0	a		9.3
																22	x	20		17	13			10	10	9	x	6	5	5	3	2	14	1	14		10.1
																23		21		18	14			11	11	10		7	6	6	4	3	x	2	15	0	10.1
																24		22		19	15			12	12	11		8	7	7	5	4		3	16	1	11.1
																25		23		20	16			13	13	12		9	8	8	6	5		4	17	2	12.1

Table A 5. MSC Cruises fleet age data

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Average Age by Year
Angelina Lauro	Achille Lauro	Monterey	Angelina Lauro II	Symphony	Rhapsody	Melody	MSC Lirica	MSC Opera	MSC Armonia	MSC Sinfonia	MSC Musica	MSC Orchestra	MSC Fantasia	MSC Poesia	MSC Splendida	MSC Magnifica	MSC Divina	MSC Preziosa	
e	e																		[-]
27	27																		27.0
28	28																		28.0
29	29																		29.0
30	30																		30.0
31	31																		31.0
32	32																		32.0
33	33																		33.0
34	34																		34.0
35	35																		35.0
36	36																		36.0
37	37																		37.0
38	38																		38.0
39	39																		39.0
40	40																		40.0
x	41																		41.0
	42																		42.0
	43																		43.0
	44																		44.0
	45																		45.0
	46																		46.0
	47																		47.0
	48																		48.0
	49	a	a																49.0
	50	37	21																36.0
	51	38	22																37.0
	52	39	23																38.0
	53	40	x																46.5
	54	41		a															47.5
	55	42		43	a														46.7
	x	43		44	21	a													36.0
		44		45	22	15													31.5
		45		46	23	16													32.5
		46		47	24	17													33.5
		47		48	25	18													34.5
		48		49	26	19													35.5
		49		x	27	20													32.0
		50			28	21													33.0
		51			29	22	0		a	a									25.5
		52			30	23	1	0	3	2									15.9
		53			31	24	2	1	4	3									16.9
		54			32	25	3	2	5	4	0								15.6
		55			33	26	4	3	6	5	1	0							14.8
		x			34	27	5	4	7	6	2	1	0	0					8.6
					35	28	6	5	8	7	3	2	1	1	0				8.7
					x	29	7	6	9	8	4	3	2	2	1	0			6.5
						30	8	7	10	9	5	4	3	3	2	1			7.5
						31	9	8	11	10	6	5	4	4	3	2	0		7.8
						32	10	9	12	11	7	6	5	5	4	3	1	0	8.1
						x	11	10	13	12	8	7	6	6	5	4	2	1	7.1
							12	11	14	13	9	8	7	7	6	5	3	2	8.1
							13	12	15	14	10	9	8	8	7	6	4	3	9.1

Table A 6. Norwegian Cruise Line fleet age data

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Average Age by Year
Sunward	Starward	Skyward	Southward	Sunward II	Norway	Norwegian Sea	Westward	Sunward III	Norwegian Dream	Norwegian Wind	Leeward	Norwegian Crown	Norwegian Dynasty	Norwegian Star	Norwegian Majesty	Norwegian Sky**	Norwegian Sun	Norwegian Star II	Norwegian Dawn	Norwegian Spirit	Pride of America	Norwegian Jewel	Pride of Hawaii**	Norwegian Pearl	Norwegian Gem	Norwegian Epic	Norwegian Breakaway	Norwegian Getaway	Breakaway Plus	
																														[-]
0																														0.0
1																														1.0
2	0																													1.0
3	1	0																												1.3
4	2	1																												2.3
5	3	2	0																											2.5
6	4	3	1																											3.5
7	5	4	2																											4.5
8	6	5	3																											5.5
9	7	6	4																											6.5
10	8	7	5	a																										7.5
x	9	8	6	6																										7.3
	10	9	7	7	a																									8.3
	11	10	8	8	18																									11.0
	12	11	9	9	19																									12.0
	13	12	10	10	20																									13.0
	14	13	11	11	21																									14.0
	15	14	12	12	22																									15.0
	16	15	13	13	23																									16.0
	17	16	14	14	24																									17.0
	18	17	15	15	25																									18.0
	19	18	16	16	26																									19.0
	20	19	17	17	27	0																								16.7
	21	20	18	18	28	1																								17.7
	22	21	19	19	29	2	a	a																						18.7
	23	22	20	20	30	3	19	18																						19.4
	24	x	21	x	31	4	20	19	0																					17.0
	25		22		32	5	21	20	1	0																				15.8
	26		23		33	6	x	x	2	1	a																			15.2
	27		x		34	7			3	2	15	a																		14.7
	x				35	8			4	3	16	8	a	a	a															12.3
					36	9			5	4	17	9	4	24	5															12.6
					37	10			6	5	18	10	5	25	6															13.6
					38	11			7	6	19	11	6	x	7	0														11.7
					39	12			8	7	x	12	x		8	1														12.4
					40	13			9	8		x			9	2	0	0												10.1
					41	14			10	9		a			10	3	1	1	0											9.9
					42	15			11	10		15			11	4	2	2	1	a										11.3
					x	16			12	11		16			12	5	3	3	2	6										8.6
						17			13	12		17			13	6	4	4	3	7	0	0								8.0
						x			14	13		18			14	7	5	5	4	8	1	1	0							7.5
									15	14		19			15	8	6	6	5	9	2	2	1	0						7.8
									16	x		x			16	9	7	7	6	10	3	3	2	1	0					6.7
									x						17	10	8	8	7	11	4	4	3	2	1					6.8
															x	11	9	9	8	12	5	5	4	3	2	0				6.2
																12	10	10	9	13	6	6	5	4	3	1				7.2
																13	11	11	10	14	7	7	6	5	4	2				8.2
																14	12	12	11	15	8	8	7	6	5	3	0			8.4
																15	13	13	12	16	9	9	8	7	6	4	1	0		8.7
																16	14	14	13	17	10	10	9	8	7	5	2	1	0	9.0
																17	15	15	14	18	11	11	10	9	8	6	3	2	1	10.0

Table A 7. Celebrity Cruises fleet age data

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Meridian	Horizon	Zenith	Celebrity Century	Celebrity Galaxy	Celebrity Mercury	Celebrity Millenium	Celebrity Infinity	Celebrity Summit	Celebrity Constellation	Celebrity Xpedition	Celebrity Solstice	Celebtiry Equinox	Celebrity Eclipse	Celebrity Silhouette	Celebrity Reflection	**Average Age by Year**
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
																[-]
a																[-]
27	0															13.5
28	1															14.5
29	2	0														10.3
30	3	1														11.3
31	4	2														12.3
32	5	3	0													10.0
33	6	4	1	0												8.8
34	7	5	2	1	0											8.2
x	8	6	3	2	1											4.0
	9	7	4	3	2											5.0
	10	8	5	4	3	0										5.0
	11	9	6	5	4	1	0	0								4.5
	12	10	7	6	5	2	1	1	0							4.9
	13	11	8	7	6	3	2	2	1	a						5.9
	14	12	9	8	7	4	3	3	2	3						6.5
	15	13	10	9	8	5	4	4	3	4						7.5
	x	14	11	10	9	6	5	5	4	5						7.7
		15	12	11	10	7	6	6	5	6						8.7
		x	13	12	11	8	7	7	6	7	0					7.9
			14	13	12	9	8	8	7	8	1	0				8.0
			15	x	13	10	9	9	8	9	2	1	0			7.6
			16		14	11	10	10	9	10	3	2	1	0		7.8
			17		x	12	11	11	10	11	4	3	2	1	0	7.5
			18			13	12	12	11	12	5	4	3	2	1	8.5
			19			14	13	13	12	13	6	5	4	3	2	9.5
			x			15	14	14	13	14	7	6	5	4	3	9.5
						16	15	15	14	15	8	7	6	5	4	10.5

Table A 8. Holland America Line fleet age data

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Average Age by Year
Nieuw Amsterdam II	Statendam IV	Rotterdam V	Prinsendam	Veendam III	Volendam II	Nieuw Amsterdam III	Noordam III	Westerdam II	Statendam V	Maasdam V	Ryndam III	Veendam IV	Rotterdam VI	Volendam III	Zaandam	Amsterdam III	Prinsendam II	Zuiderdam	Oosterdam	Westerdam III	Noordam IV	Eurodam	Nieuw Amsterdam IV	Project Pinnacle	
																									[-]
																									[-]
																									[-]
																									[-]
																									[-]
																									[-]
																									[-]
e	e	e		a	a																				[-]
34	17	14	0	15	15																				15.8
35	18	15	1	16	16																				16.8
x	19	16	2	17	17																				14.2
	20	17	3	18	18																				15.2
	21	18	4	xa	xa																				14.3
	22	19	5	20	20																				17.2
	23	20	6	21	21																				18.2
	24	21	7	22	22																				19.2
	25	22	x	23	23																				23.3
	26	23		24	24																				24.3
	x	24		25	25	0																			18.5
		25		26	26	1	0																		15.6
		26		x	x	2	1																		9.7
		27				3	2																		10.7
		28				4	3	a																	11.7
		29				5	4	2																	10.0
		30				6	5	3																	11.0
		31				7	6	4																	12.0
		32				8	7	5																	13.0
		33				9	8	6	0																11.2
		34				10	9	7	1	0															10.2
		35				11	10	8	2	1	0														9.6
		36				12	11	9	3	2	1														10.6
		37				13	12	10	4	3	2	0													10.1
		38				14	13	11	5	4	3	1	0												9.9
		x				15	14	12	6	5	4	2	1												7.4
						16	15	13	7	6	5	3	2	0											7.4
						17	16	14	8	7	6	4	3	1	0	0									6.9
						x	17	15	9	8	7	5	4	2	1	1	a								6.9
							18	16	10	9	8	6	5	3	2	2	14	0							7.8
							19	x	11	10	9	7	6	4	3	3	15	1	0						7.3
							20		12	11	10	8	7	5	4	4	16	2	1	0					7.7
							21		13	12	11	9	8	6	5	5	17	3	2	1					8.7
							x		14	13	12	10	9	7	6	6	18	4	3	2	0				8.0
									15	14	13	11	10	8	7	7	19	5	4	3	1				9.0
									16	15	14	12	11	9	8	8	20	6	5	4	2	0			9.3
									17	16	15	13	12	10	9	9	21	7	6	5	3	1			10.3
									18	17	16	14	13	11	10	10	22	8	7	6	4	2	0		10.5
									19	18	17	15	14	12	11	11	23	9	8	7	5	3	1		11.5
									20	19	18	16	15	13	12	12	24	10	9	8	6	4	2		12.5
									21	20	19	17	16	14	13	13	25	11	10	9	7	5	3		13.5
									22	21	20	18	17	15	14	14	26	12	11	10	8	6	4		14.5
									23	22	21	19	18	16	15	15	27	13	12	11	9	7	5		15.5
									24	23	22	20	19	17	16	16	28	14	13	12	10	8	6	0	15.5

Table A 9. AIDA Cruises fleet age data

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average Age by Year
Völkerfreundschaft	Arcona	AIDAcara*	AIDAvita	AIDAura	AIDAblu	AIDAdiva	AIDAbella	AIDAluna	AIDAblu II	AIDAsol	AIDAmar	AIDAstella	New1	New2	
e															[-]
18															18.0
19															19.0
20															20.0
21															21.0
22															22.0
23															23.0
24															24.0
25															25.0
26															26.0
27															27.0
28															28.0
29															29.0
30															30.0
31															31.0
32															32.0
33															33.0
34															34.0
35															35.0
36	a														36.0
37	4														20.5
x	5														5.0
	6														6.0
	7														7.0
	8														8.0
	9														9.0
	10														10.0
	11														11.0
	12														12.0
	13														13.0
	14														14.0
	15	0													7.5
	x	1													1.0
		2													2.0
		3													3.0
		4													4.0
		5													5.0
		6	0												3.0
		7	1	0	a										2.7
		8	2	1	14										6.3
		9	3	2	15										7.3
		10	4	3	16										8.3
		11	5	4	17	0									7.4
		12	6	5	x	1	0								4.8
		13	7	6		2	1	0							4.8
		14	8	7		3	2	1	0						5.0
		15	9	8		4	3	2	1	0					5.3
		16	10	9		5	4	3	2	1	0				5.6
		17	11	10		6	5	4	3	2	1	0			5.9
		18	12	11		7	6	5	4	3	2	1			6.9
		19	13	12		8	7	6	5	4	3	2	0		7.2
		20	14	13		9	8	7	6	5	4	3	1	0	7.5

Table A 10. P&O Cruises fleet age data

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Average Age by Year
Arcadia II	Oriana	Canberra	Spirit of London	Victoria	Oriana II	Arcadia III	Aurora	Oceana	Adonia	Arcadia IV	Artemis	Ventura	Azura	Adonia II	Britannia	
e	e	e														[-]
12	7	6														8.3
13	8	7														9.3
14	9	8														10.3
15	10	9														11.3
16	11	10														12.3
17	12	11														13.3
18	13	12	0													10.8
19	14	13	1													11.8
20	15	14	3													13.0
21	16	15	x													17.3
22	17	16														18.3
23	18	17														19.3
24	19	18		a												20.3
25	20	19		13												19.3
x	21	20		14												18.3
	22	21		15												19.3
	23	22		16												20.3
	24	23		17												21.3
	25	24		18												22.3
	26	25		19												23.3
	27	26		20												24.3
	x	27		x												27.0
		28														28.0
		29														29.0
		30														30.0
		31														31.0
		32														32.0
		33														33.0
		34		a												34.0
		35		29	0											21.3
		36		30	1	a										22.3
		37		31	2	8										19.5
		x		32	3	9										14.7
				33	4	10										15.7
				34	5	11	0									12.5
				35	6	12	1	a								13.5
				36	7	13	2	2	a							12.0
				x	8	14	3	3	5							6.6
					9	x	4	4	6		a					5.8
					10		5	5	7	0	21					8.0
					11		6	6	x	1	22					9.2
					12		7	7		2	23					10.2
					13		8	8		3	24	0				9.3
					14		9	9		4	25	1				10.3
					15		10	10		5	26	2	0	a		9.7
					16		11	11		6	27	3	1	10		10.6
					17		12	12		7	x	4	2	11		9.3
					18		13	13		8		5	3	12		10.3
					19		14	14		9		6	4	13		11.3
					20		15	15		10		7	5	14	0	10.8
					21		16	16		11		8	6	15	1	11.8

Appendix B – Reference conversion tasks

Table A 11. Conversion case definitions

Conversion Case	Description
0	minor refurbishment not reflected in the thesis scope
1	former large space into multiple smaller ones
2	former small spaces into single larger one
3	open deck rebuilding
4	concentrated, heavy conversion addition

Table A 12. Brilliance of the Seas conversion tasks

	Conversion Task	Description	Location	Conversion Case
1	Lounge reconfiguration	Viking Crown Lounge seperated into smaller, divided spaces	deck 13 mid	1
2	Pool deck enhancement	Movie screen and related structures added	deck 12 mid	4
3	Lounge conversion	Centrum Lounge converted into winch system equipment room	deck 12 mid	4
4	Restaurant reclassification	Seaview Cafe converted into Izumi sushi restaurant	deck 12 aft	0
5	Lounge conversion	Country Club and adjacent spaces converted into arcade	deck 12 aft	2
6	Space reclassification	Arcade converted into Nursery	deck 12 mid	0
7	Open deck conversion	Open Deck converted into Rita's Cantina restaurant	deck 11 aft	3
8	Lounge conversion	Concierge Club converted into passenger suite	deck 10 mid	1
9	Lounge conversion	Yacht Club converted into passenger cabin	deck 10 mid	1
10	Service space conversion	Bell box galley converted into passenger cabins	deck 9 for.	1
11	Lounge conversion	Library converted into passenger cabin	deck 9 mid	1
12	Lounge conversion	Explorer's Court converted into passenger cabin	deck 8 mid	1
13	Space reclassification	Bar and lounge converted into pub	deck 6 for.	0
14	Space reclassification	Champagne Bar converted into Vintages bar	deck 6 mid	0
15	Restaurant reclassification	Portofino restaurant converted into Giovanni's Table	deck 6 aft	0
16	Lounge conversion	Card Room converted into Chef's Table dining room	deck 6 aft	0
17	Restaurant conversion	Zephyr Dining Room converted into passenger cabins	deck 4 mid	1

Table A 13. Disney Magic conversion tasks

	Conversion Task	Description	Location	Conversion Case
1	Sun deck enhancement	Forward thrill water slide and related structures added	deck 11 mid	4
2	Pool deck enhancement	Aft water slide added and related structures modified	deck 11 aft	4
3	Restaurant enlargement	Topsiders buffet extended onto deck space; renamed Cabana's	deck 9 aft	3
4	WC conversion	WC converted into water slide pump room	deck 9 mid	0
5	Salon enlargement	Beauty Salon extended onto open deck space	deck 9 for.	3
6	Open deck conversion	Open deck space converted into store rooms and public spaces	deck 9 for.	3
7	ADA corrections	Existing cabins converted into ADA compliant cabins	various decks	0
8	Cabin enlargememt	Cabin and adjacent stair space converted into single cabin	deck 8 aft	2
9	Open deck conversion	Open deck space converted into EDG room	deck 7 aft	3
10	Space reconfiguration	Kid's facilities seperated into smaller, divided spaces	deck 5 mid	1
11	Space reconfiguration	Nursery and adjacent spaces converted into single nursery space	deck 5 mid	2
12	Space reclassification	Parrot Cay restaurant refurbished into Carioca's restaurant	deck 3 aft	0
13	Sponson-ducktail addition	Stability enhancement measure	WL aft	3

Table A 14. Carnival Sunshine conversion tasks

	Conversion Task	Description	Location	Conversion Case
1	Partial deck addition	Partial decks built and serenity deck areas extended	D 11,12,14 for.	4
2	Open deck conversion	Open deck space converted into cabin area	deck 12 for.	3
3	Space conversion	Kid's facilities converted into cabin area	deck 12 for.	1
4	Serenity deck	Pool added	deck 11 for.	4
5	Sun deck enhancement	Mini golf, sports court, and water slides added	deck 10,11 aft	4
6	Restaurant conversion	Sun & Sea Restaurant converted into kid's facilities	deck 10 aft	1
7	Open deck conversion	Open deck space converted into cabin area	deck 10 mid	3
8	Space conversion	Kid's facilities converted into spa area	deck 10 for.	0
9	Space conversion	Salon and sauna converted into cabin area	deck 10 for.	1
10	Space reconfiguration	Spa laout reconfigured	deck 10 for.	0
11	Open deck conversion	Open deck space converted into cabin area	deck 9 for.	3
12	Pool deck enhancement	Deck bar areas added	deck 9 mid	4
13	Space reclassification	Deck dining spaces modified	deck 9 mid	0
14	Open deck conversion	Pool deck converted into restaurant spaces	deck 9 aft	3
15	Space reconfiguration	Casino divided into seperate casino and arcade spaces	deck 5 mid	1
16	Lounge reconfiguration	Point After dance club divided into restaurant and lounge spaces	deck 5 aft	1
17	Lounge reconfiguration	Criterion Lounge converted into cabin area	deck 5 aft	1
18	Restaurant conversion	Galaxy dining room upper level converted into seperate spaces	deck 4 mid	1
19	Lounge reconfiguration	Main theater ground level converted into cabin space	deck 3 for.	1

Appendix C – SOLAS fire integrity categories

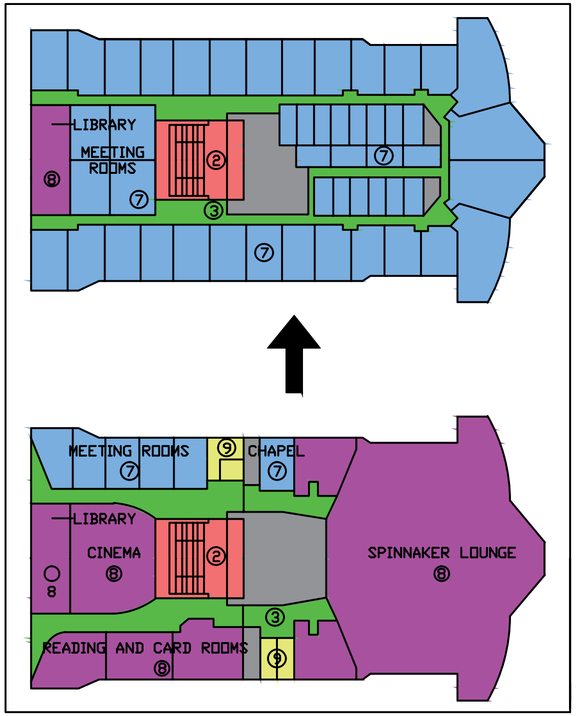
Table A 15. SOLAS space categories by fire integrity class

Source: adapted from [96] Chapter 2.2.3.2

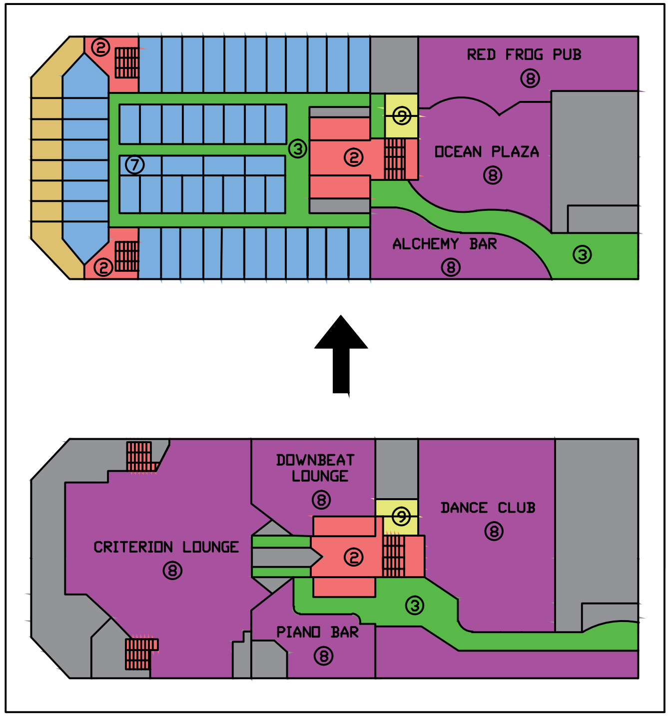
Category	Description	Applicable spaces (consolidated)
1	control stations	wheelhouse and chartroom
		spaces containing emergency power, radio equipment, fire alarm equip.
		spaces containing public address system equipment, fire control
		propulsion machinery control spaces outside main machinery spaces
2	stairways	interior stairways, lifts, escape trunks, escalators and related enclosures
3	corridors	passenger and crew corridors and lobbies
4	evacuation stations and external escape routes	assembly stations
		external stairs and open decks used for escape
		open deck and promenade spaces forming lifeboat stations
5	open deck spaces	open decks
		enclosed promenades with no significant fire risk
6	accommodation spaces of minor fire risk	cabins of restricted fire risk
		offices of restricted fire risk
		public spaces of restricted fire risk of less than 50 m2 area
7	accommodation spaces of moderate fire risk	spaces in cat. 6 with furnishings of other than restricted fire risk
		public spaces of moderate fire risk of less than 50 m2 area
		sale shops and isolated lockers of less than 4 m2 area
8	accommodation spaces of greater fire risk	public spaces of 50 m2 area or more
		barber shops and beauty parlors
		saunas
9	sanitary and similar spaces	communal sanitary facilities
		small laundry rooms, indoor swimming pool areas, isolated pantries
10	tanks, voids, auxiliary machy spaces of low fire risk	water tanks forming ship's structure
		voids and cofferdams
		restricted auxiliary machinery spaces
11	auxiliary machy spaces, cargo spaces and similar spaces of moderate fire risk	cargo oil tanks, holds, and hatchways
		refrigerated chambers
		specified oil fuel tanks, auxiliary machinery spaces
		oil fuel filling stations, etc.
12	machinery spaces and main galleys	main propulsion machinery rooms and boiler rooms
		specified auxiliary machinery spaces
		main galleys and annexes
13	store rooms, workshops, pantries, etc.	main pantries not annexed to galleys
		main laundry, drying rooms, stores
		garbage rooms, workshops, provisions stores
		lockers and stores of greater than 4 m2 area
14	other spaces in which flammable liquids are stowed	paint lockers
		store rooms containing flammable liquids
		laboratories, etc. containing flammable liquids

Appendix D – Conversion case examples

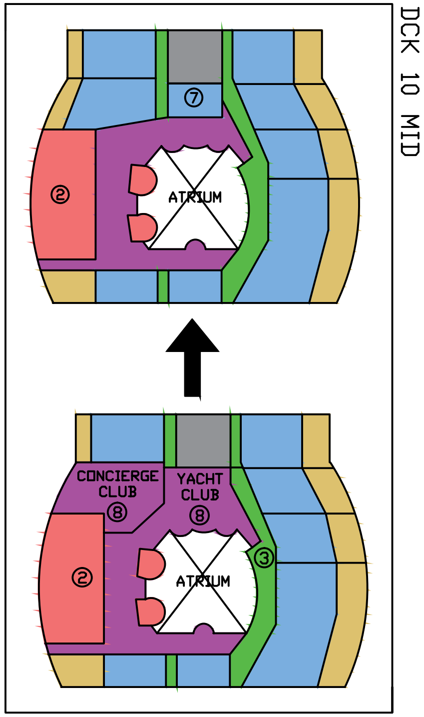
EX. 1: NORWEGIAN STAR DCK 12 FWD



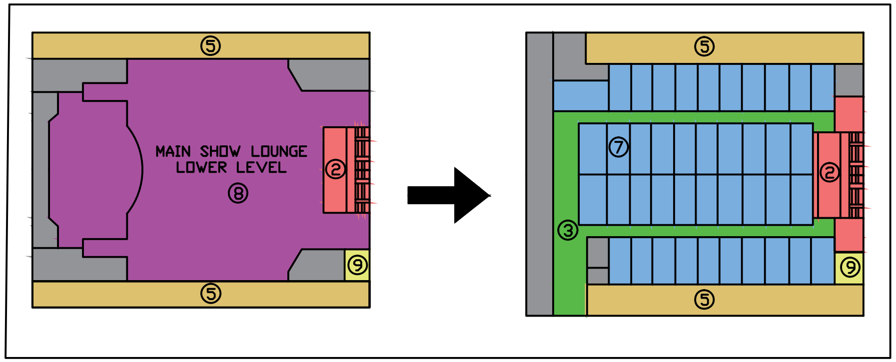
EX. 2: CARNIVAL SUNSHINE DCK 5 AFT



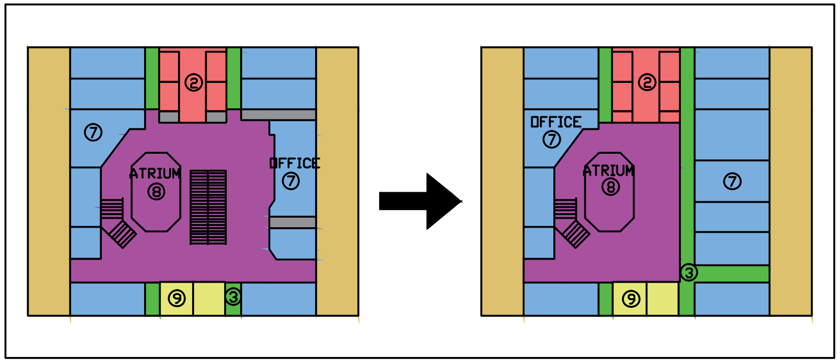
EX. 3: BRILLIANCE O.T.S



EXAMPLE 6: CARNIVAL SUNSHINE DCK 3 FWD



EXAMPLE 5: VEENDAM DCK 6 MID



Scale NTS

Aalto University
School of Engineering

Date 09.06.2014

Name JUSTIN CHAMPION

Page 1 Of 3

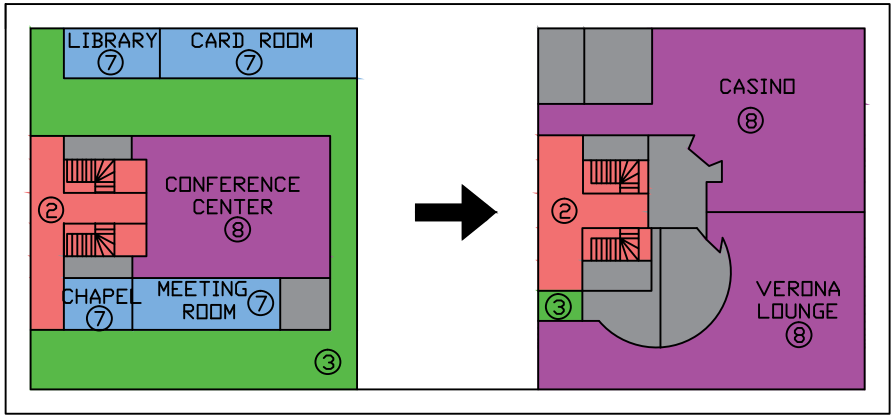
CONVERSION EXAMPLES
CASE 1

Large public space divided into multiple smaller

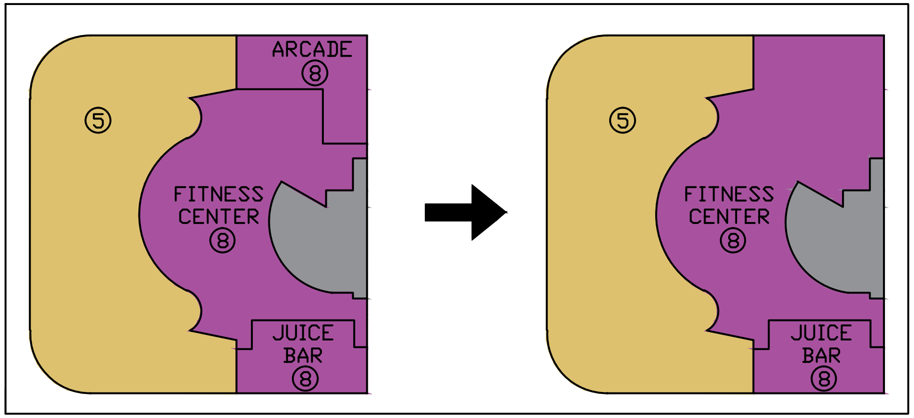
COMMON FIRE INTEGRITY SPACE CLASSES

2	STAIRWAYS
3	CORRIDORS
5	OPEN DECK SPACES
7	CABINS AND PUBLIC SPACES OF AREA LESS THAN 50 M2
8	CABINS AND PUBLIC SPACES OF AREA 50 M2 OR MORE
9	SANITARY FACILITIES
12	GALLEYS AND MAIN MACHINERY SPACES
−	MISC. OR UNKNOWN SERVICE SPACES

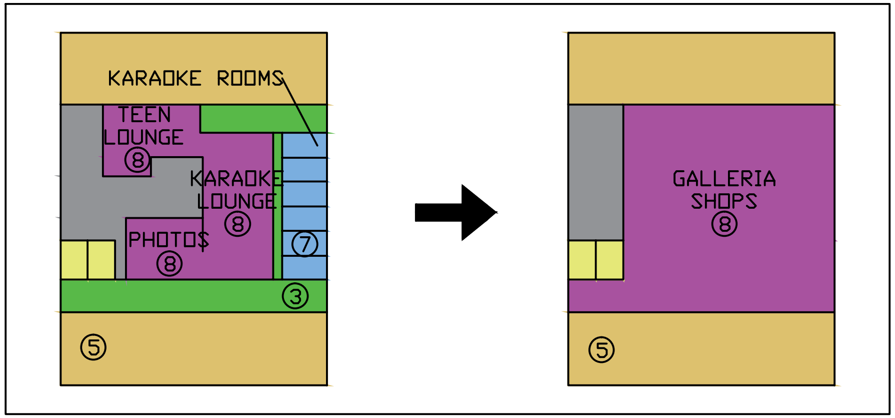
EX. 1: COSTA NEOROMANTICA DCK 8 MID



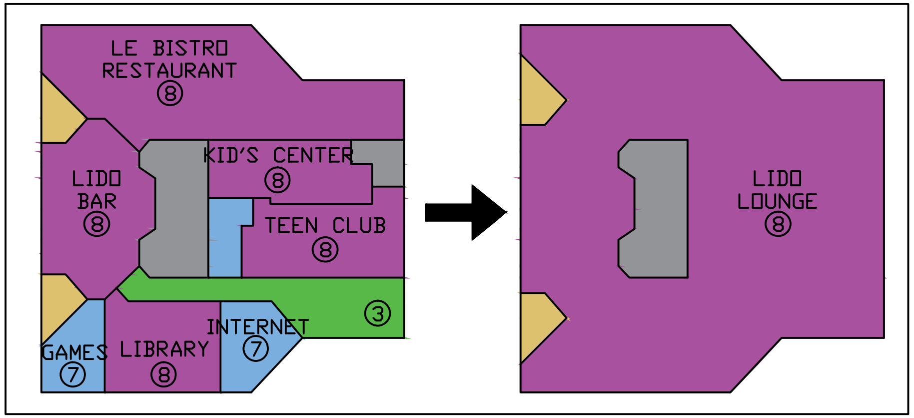
EX. 2: NORWEGIAN STAR D12 AFT



EX. 3: NORWEGIAN STAR DCK 7 FWD



EX. 4: BALMORAL DCK 8 AFT



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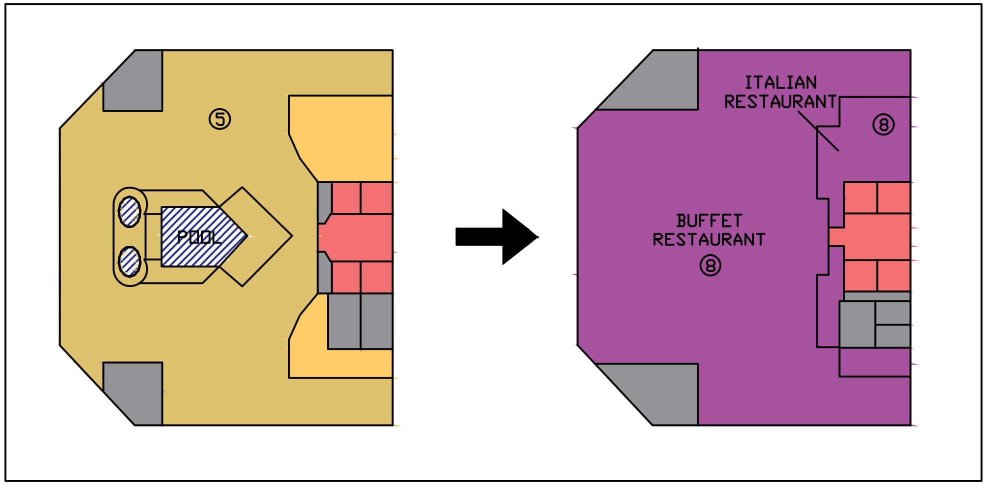
Date: 09.06.2014	CONVERSION EXAMPLES CASE 2
Name: JUSTIN CHAMPION	Small public spaces converged into single larger
Page: 2 Of: 3	

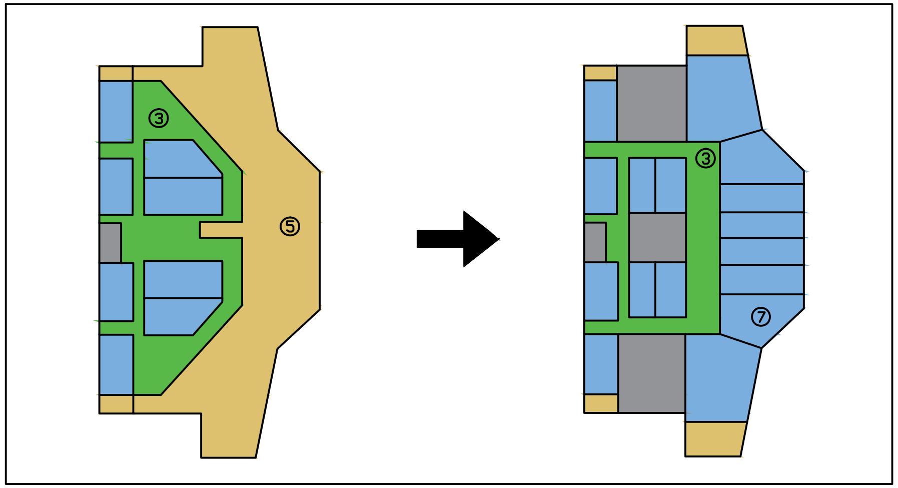
COMMON FIRE INTEGRITY SPACE CLASSES

②	STAIRWAYS
③	CORRIDORS
⑤	OPEN DECK SPACES
⑦	CABINS AND PUBLIC SPACES OF AREA LESS THAN 50 M2
⑧	CABINS AND PUBLIC SPACES OF AREA 50 M2 OR MORE
⑨	SANITARY FACILITIES
⑫	GALLEYS AND MAIN MACHINERY SPACES
⊖	MISC. OR UNKNOWN SERVICE SPACES

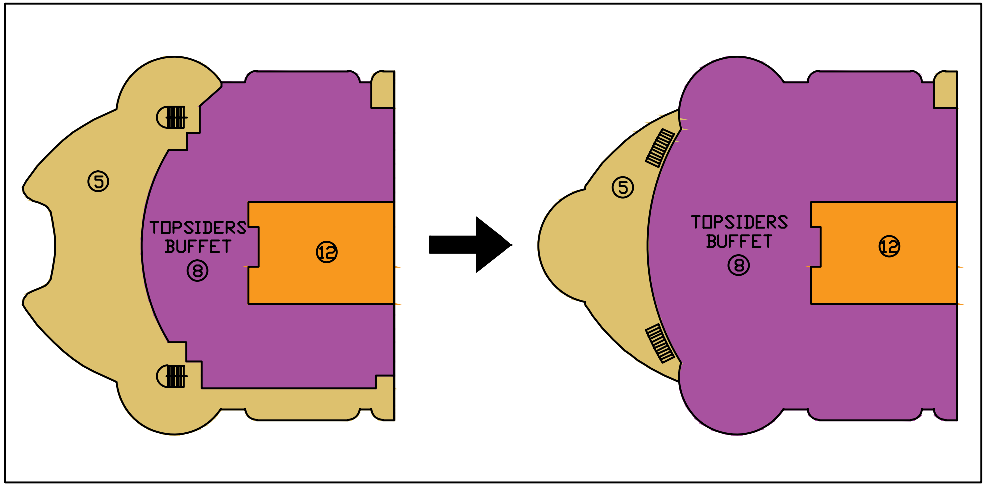
EX. 1: CARNIVAL SUNSHINE DCK 9 AFT



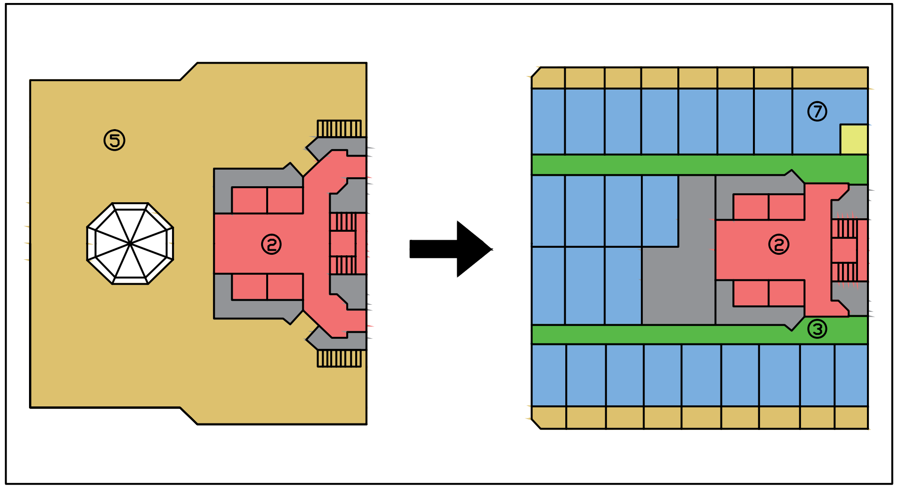
EX. 2: CARNIVAL SUNSHINE DCK 9 FWD



EX. 3: DISNEY MAGIC DCK 9 AFT



EX. 4: ARCADIA DCK 10 FWD



Scale: NTS	**Aalto University** School of Engineering
Date: 09.06.2014	CONVERSION EXAMPLES CASE 3
Name: JUSTIN CHAMPION	Rebuilding of an open deck space
Page: 3 Of: 3	

COMMON FIRE INTEGRITY SPACE CLASSES

2	STAIRWAYS
3	CORRIDORS
5	OPEN DECK SPACES
7	CABINS AND PUBLIC SPACES OF AREA LESS THAN 50 M2
8	CABINS AND PUBLIC SPACES OF AREA 50 M2 OR MORE
9	SANITARY FACILITIES
12	GALLEYS AND MAIN MACHINERY SPACES
–	MISC. OR UNKNOWN SERVICE SPACES

Appendix E – SOLAS thermal and structural boundary tables

Table A 16. SOLAS bulkhead insulation requirements

Source: based on [96] Table 9.1

Spaces		1	2	3	4	5	6	7	8	9	10	11	12	13	14
control stations	1	B-0[a]	A-0	A-0	A-0	A-0	A-60	A-60	A-60	A-0	A-0	A-60	A-60	A-60	A-60
stairways	2		A-0[a]	A-0	A-0	A-0	A-0	A-15	A-15	A-0[c]	A-0	A-15	A-30	A-15	A-30
corridors	3			B-15	A-60	A-0	B-15	B-15	B-15	B-15	A-0	A-15	A-30	A-0	A-30
evacuation stations and external escape routes	4					A-0	A-60[b,d]	A-60[d]	A-60[d]	A-0[d]	A-0	A-60[b]	A-60[b]	A-60[b]	A-60[b]
open deck spaces	5						A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
accomodation spaces of minor fire risk	6						B-0	B-0	B-0	C	A-0	A-0	A-30	A-0	A-30
accommodation spaces of moderate fire risk	7							B-0	B-0	C	A-0	A-15	A-60	A-15	A-60
accommodation spaces of greater fire risk	8								B-0	C	A-0	A-30	A-60	A-15	A-60
sanitary and similar spaces	9									C	A-0	A-0	A-0	A-0	A-0
tanks, voids and auxiliary machinery spaces having little or no fire risk	10										A-0[a]	A-0	A-0	A-0	A-0
auxiliary machinery spaces, cargo spaces, cargo and other oil tanks and other similar spaces of moderate fire risk	11											A-0[a]	A-0	A-0	A-15
machinery spaces and main galleys	12												A-0[a]	A-0	A-60
store rooms, workshops, pantries, etc.	13													A-0[a]	A-0
other spaces in which flammable liquids are stowed	14														A-30

Table A 17. SOLAS deck insulation requirements

Source: based on [96] Table 9.2

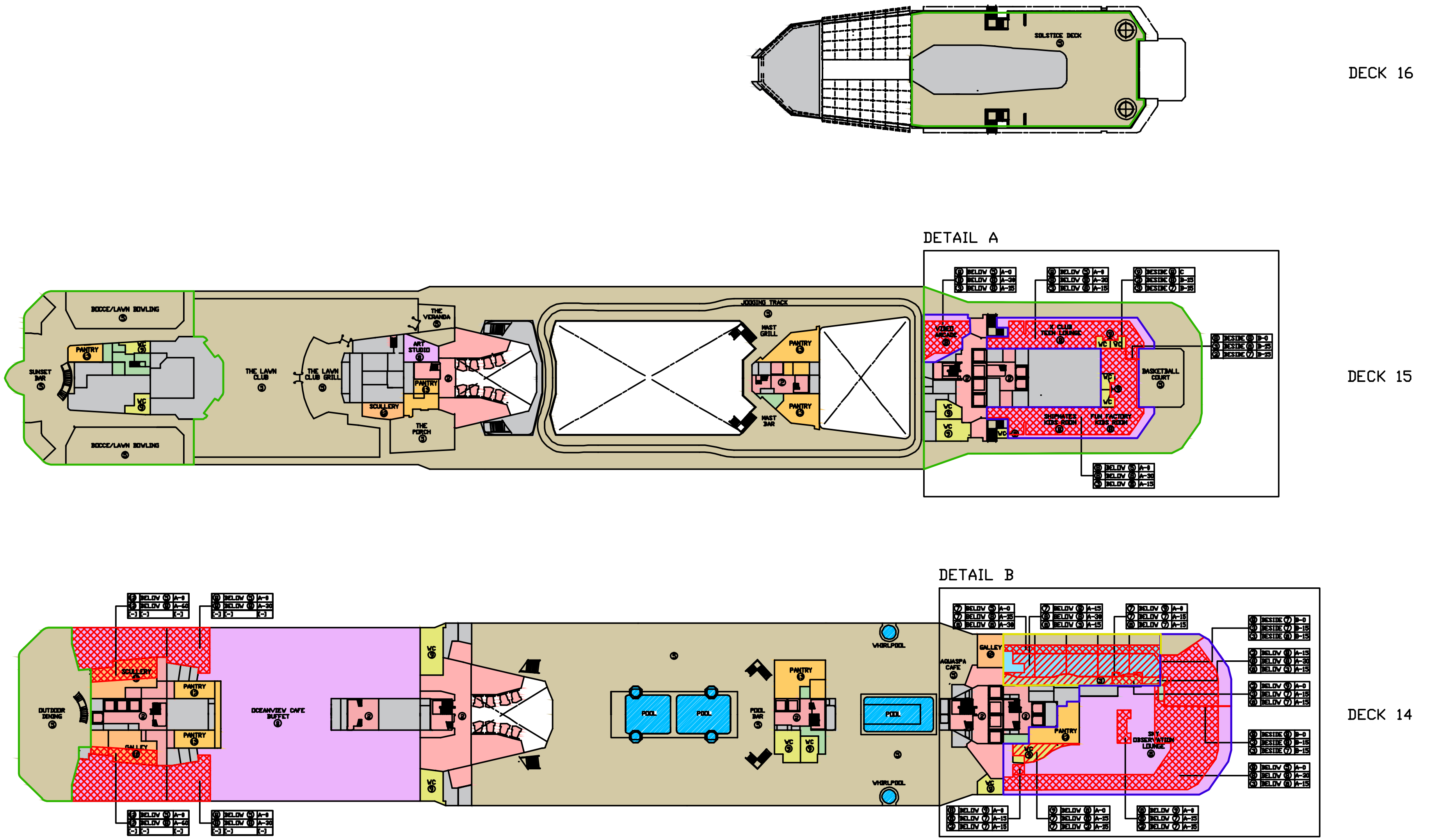
Spaces Below ↓	Spaces Above →	1	2	3	4	5	6	7	8	9	10	11	12	13	14
control stations	1	A-30	A-30	A-15	A-0	A-0	A-0	A-15	A-30	A-0	A-0	A-0	A-60	A-0	A-60
stairways	2	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-30	A-0	A-30
corridors	3	A-15	A-0	A-0[a]	A-60	A-0	A-0	A-15	A-15	A-0	A-0	A-0	A-30	A-0	A-30
evacuation stations and external escape routes	4	A-0	A-0	A-0	A-0	[-]	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
open deck spaces	5	A-0	A-0	A-0	A-0	[-]	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
accomodation spaces of minor fire risk	6	A-60	A-15	A-0	A-60	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
accommodation spaces of moderate fire risk	7	A-60	A-15	A-15	A-60	A-0	A-0	A-15	A-15	A-0	A-0	A-0	A-0	A-0	A-0
accommodation spaces of greater fire risk	8	A-60	A-15	A-15	A-60	A-0	A-15	A-15	A-30	A-0	A-0	A-0	A-0	A-0	A-0
sanitary and similar spaces	9	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
tanks, voids and auxiliary machinery spaces having little or no fire risk	10	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0[a]	A-0	A-0	A-0	A-0
auxiliary machinery spaces, cargo spaces, cargo and other oil tanks and other similar spaces of moderate fire risk	11	A-60	A-60	A-60	A-60	A-0	A-0	A-15	A-30	A-0	A-0	A-0[a]	A-0	A-0	A-30
machinery spaces and main galleys	12	A-60	A-60	A-60	A-60	A-0	A-60	A-60	A-60	A-0	A-0	A-60	A-30[a]	A-0	A-60
store rooms, workshops, pantries, etc.	13	A-60	A-30	A-15	A-60	A-0	A-15	A-30	A-30	A-0	A-0	A-0	A-0	A-0	A-0
other spaces in which flammable liquids are stowed	14	A-60	A-60	A-60	A-60	A-0	A-30	A-60	A-60	A-0	A-0	A-0	A-0	A-0	A-0

Table A 18. Fire integrity reinforcement table

Source: adapted from [96] Table 9.1 and Table 9.2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Below 1	A-30	A-0	A-15	A-0	A-0	A-60	A-60	A-60	A-0	A-0	A-60	A-60	A-60	A-60
Above 1	A-30	A-30	A-15	A-0	A-0	A-0	A-15	A-30	A-0	A-0	A-0	A-60	A-0	A-60
Beside 1	B-0[a]	A-0	A-0	A-0	A-0	A-60	A-60	A-60	A-0	A-0	A-60	A-60	A-60	A-60
Below 2	A-30	A-0	A-0	A-0	A-0	A-15	A-15	A-15	A-0	A-0	A-60	A-60	A-30	A-60
Above 2	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-30	A-0	A-30
Beside 2	A-0	A-0[a]	A-0	A-0	A-0	A-0	A-15	A-15	A-0[c]	A-0	A-15	A-30	A-15	A-30
Below 3	A-15	A-0	A-0[a]	A-0	A-0	A-0	A-15	A-15	A-0	A-0	A-60	A-60	A-15	A-60
Above 3	A-15	A-0	A-0[a]	A-60	A-0	A-0	A-15	A-15	A-0	A-0	A-0	A-30	A-0	A-30
Beside 3	A-0	A-0	B-15	A-60	A-0	B-15	B-15	B-15	B-15	A-0	A-15	A-30	A-0	A-30
Below 4	A-0	A-0	A-60	A-0	A-0	A-60	A-60	A-60	A-0	A-0	A-60	A-60	A-60	A-60
Above 4	A-0	A-0	A-0	A-0	[-]	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Beside 4	A-0	A-0	A-60		A-0	B-15	B-15	B-15	B-15	A-0	A-15	A-30	A-0	A-30
Below 5	A-0	A-0	A-0	[-]	[-]	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Above 5	A-0	A-0	A-0	A-0	[-]	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Beside 5	A-0	A-0	A-0	A-0	[-]	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Below 6	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-15	A-0	A-0	A-0	A-60	A-15	A-30
Above 6	A-60	A-15	A-0	A-60	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Beside 6	A-60	A-0	B-15	A-60[b,d]	A-0	B-0	B-0	B-0	C	A-0	A-0	A-30	A-0	A-30
Below 7	A-15	A-0	A-15	A-0	A-0	A-0	A-15	A-15	A-0	A-0	A-15	A-60	A-30	A-60
Above 7	A-60	A-15	A-15	A-60	A-0	A-0	A-15	A-15	A-0	A-0	A-0	A-0	A-0	A-0
Beside 7	A-60	A-15	B-15	A-60[d]	A-0	B-0	B-0	B-0	C	A-0	A-15	A-60	A-15	A-60
Below 8	A-30	A-0	A-15	A-0	A-0	A-0	A-15	A-30	A-0	A-0	A-30	A-60	A-30	A-60
Above 8	A-60	A-15	A-15	A-60	A-0	A-15	A-15	A-30	A-0	A-0	A-0	A-0	A-0	A-0
Beside 8	A-60	A-15	B-15	A-60	A-0	B-0	B-0	B-0	C	A-0	A-30	A-60	A-15	A-60
Below 9	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Above 9	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Beside 9	A-0	A-0[c]	B-15	A-0[d]	A-0	C	C	C	C	A-0	A-0	A-0	A-0	A-0
Below 10	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0[a]	A-0	A-0	A-0	A-0
Above 10	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0[a]	A-0	A-0	A-0	A-0
Beside 10	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0[a]	A-0	A-0	A-0	A-0
Below 11	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0[a]	A-60	A-0	A-0
Above 11	A-60	A-60	A-60	A-60	A-0	A-0	A-15	A-30	A-0	A-0	A-0[a]	A-0	A-0	A-30
Beside 11	A-60	A-15	A-15	A-60[b]	A-0	A-0	A-15	A-30	A-0	A-0	A-0[a]	A-0	A-0	A-15
Below 12	A-60	A-30	A-30	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-30[a]	A-0	A-0
Above 12	A-60	A-60	A-60	A-60	A-0	A-60	A-60	A-60	A-0	A-0	A-60	A-30[a]	A-0	A-60
Beside 12	A-60	A-30	A-30	A-60[b]	A-0	A-30	A-60	A-60	A-0	A-0	A-0	A-0[a]	A-0	A-60
Below 13	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0
Above 13	A-60	A-30	A-15	A-60	A-0	A-15	A-30	A-30	A-0	A-0	A-0	A-0	A-0	A-0
Beside 13	A-60	A-15	A-0	A-60[b]	A-0	A-0	A-15	A-15	A-0	A-0	A-0	A-0	A-0[a]	A-0
Below 14	A-60	A-30	A-30	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-30	A-60	A-0	A-0
Above 14	A-60	A-60	A-60	A-60	A-0	A-30	A-60	A-60	A-0	A-0	A-0	A-0	A-0	A-0
Beside 14	A-60	A-30	A-30	A-60[b]	A-0	A-30	A-60	A-60	A-0	A-0	A-15	A-60	A-0	A-30

Appendix F – Case study drawings



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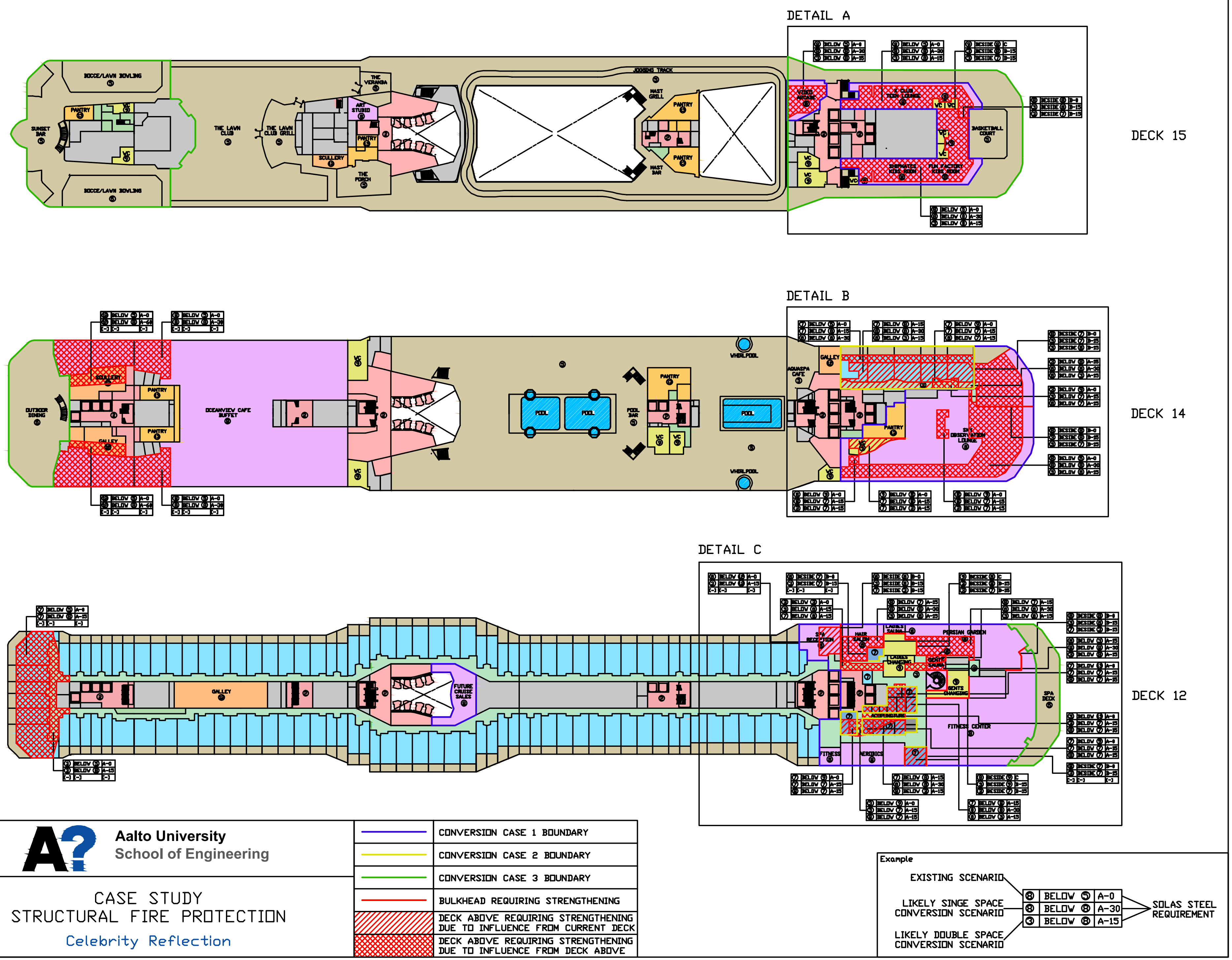
CASE STUDY
STRUCTURAL FIRE PROTECTION
Celebrity Reflection

	CONVERSION CASE 1 BOUNDARY
	CONVERSION CASE 2 BOUNDARY
	CONVERSION CASE 3 BOUNDARY
	BULKHEAD REQUIRING STRENGTHENING
	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM CURRENT DECK
	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM DECK ABOVE

Example

EXISTING SCENARIO — ⑫ BELOW ⑤ A-0
LIKELY SINGE SPACE CONVERSION SCENARIO — ⑧ BELOW ⑧ A-30
LIKELY DOUBLE SPACE CONVERSION SCENARIO — ③ BELOW ⑧ A-15
SOLAS STEEL REQUIREMENT



	CONVERSION CASE 1 BOUNDARY
	CONVERSION CASE 2 BOUNDARY
	CONVERSION CASE 3 BOUNDARY
	BULKHEAD REQUIRING STRENGTHENING
	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM CURRENT DECK
	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM DECK ABOVE

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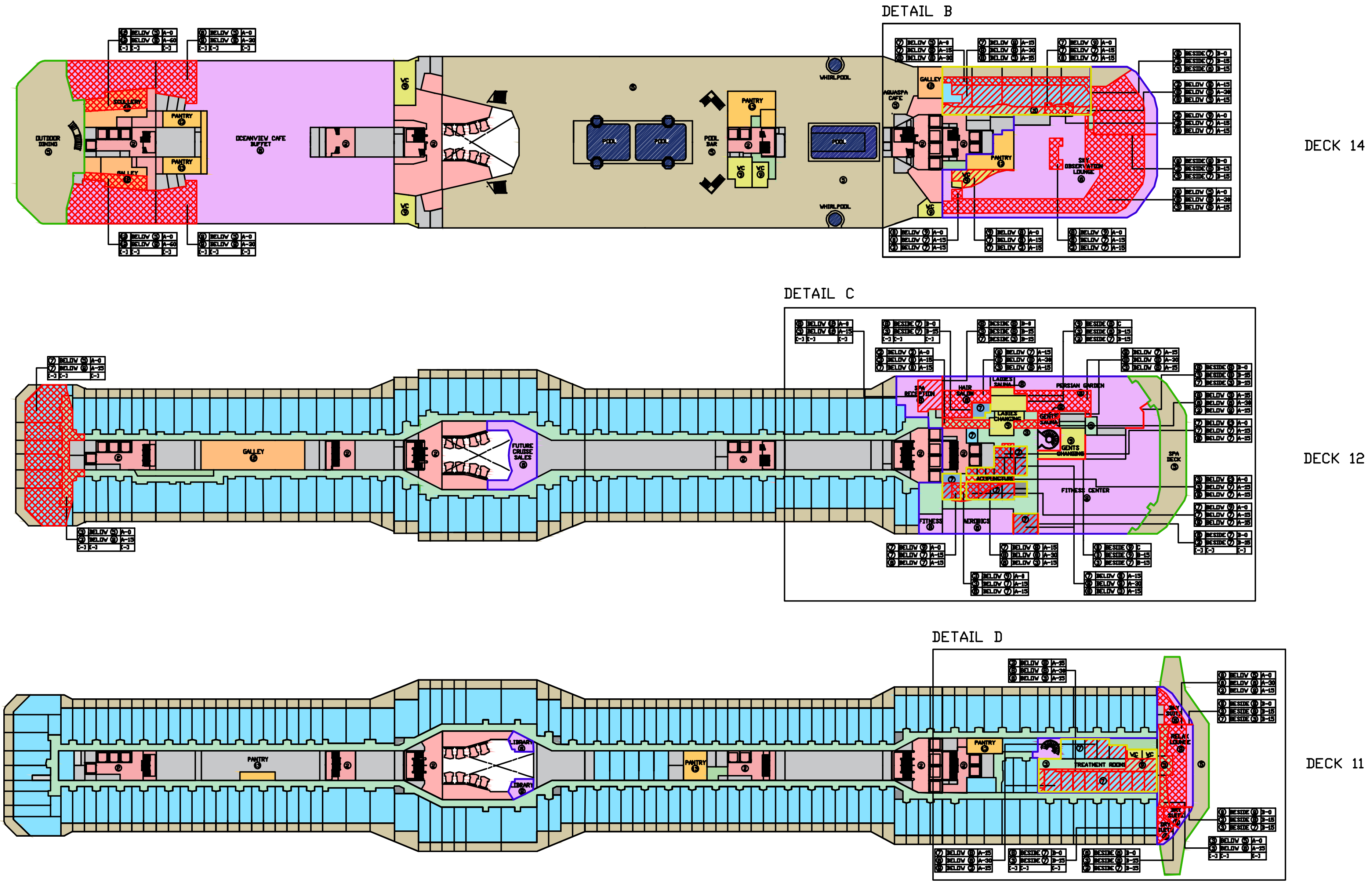

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CASE STUDY
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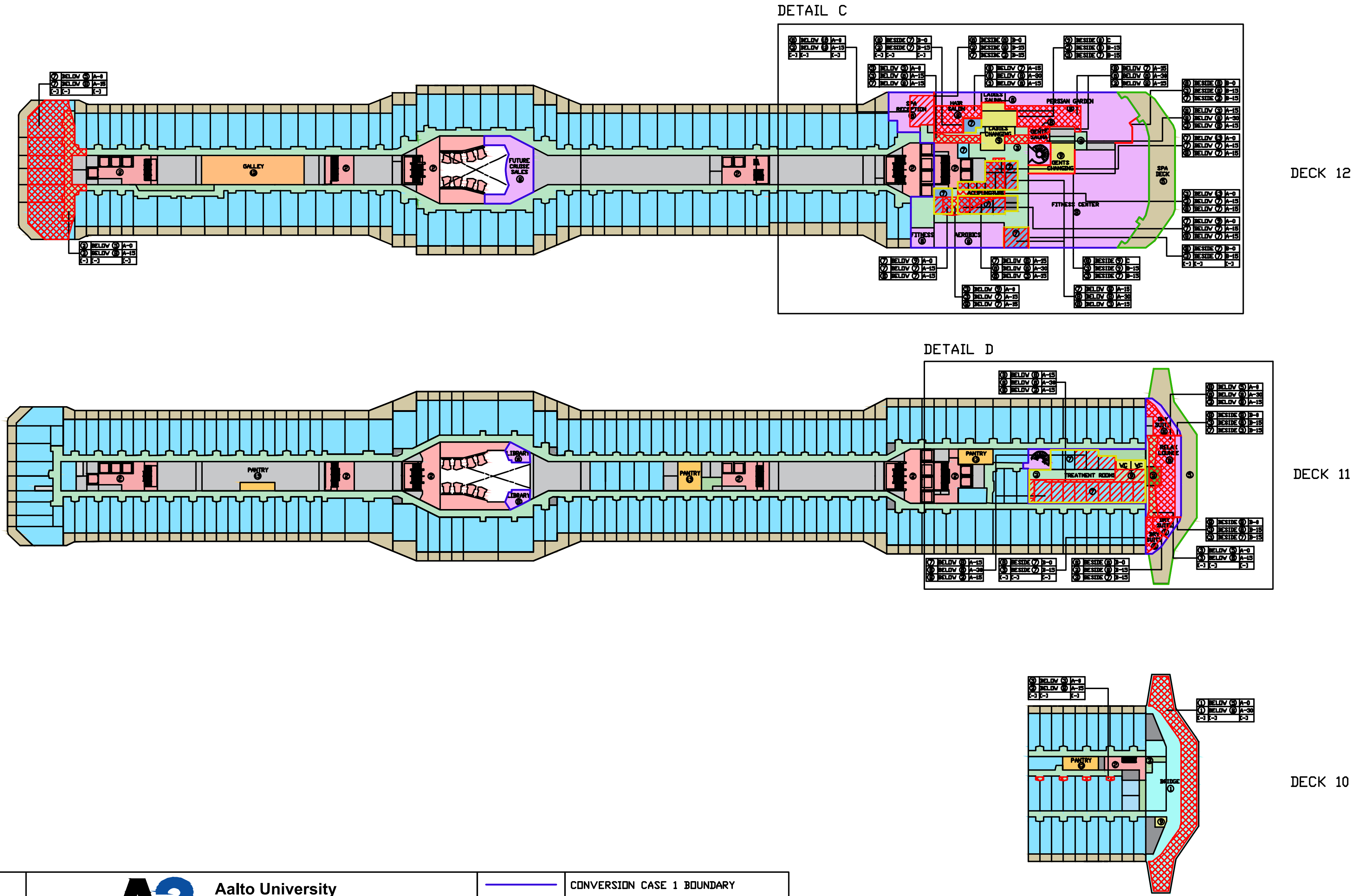
Blue line	CONVERSION CASE 1 BOUNDARY
Yellow line	CONVERSION CASE 2 BOUNDARY
Green line	CONVERSION CASE 3 BOUNDARY
Red line	BULKHEAD REQUIRING STRENGTHENING
Red diagonal hatch	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM CURRENT DECK
Red cross hatch	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM DECK ABOVE

Example

EXISTING SCENARIO
LIKELY SINGE SPACE CONVERSION SCENARIO
LIKELY DOUBLE SPACE CONVERSION SCENARIO

6	BELOW	5	A-0	SOLAS STEEL REQUIREMENT
6	BELOW	8	A-30	
3	BELOW	8	A-15	



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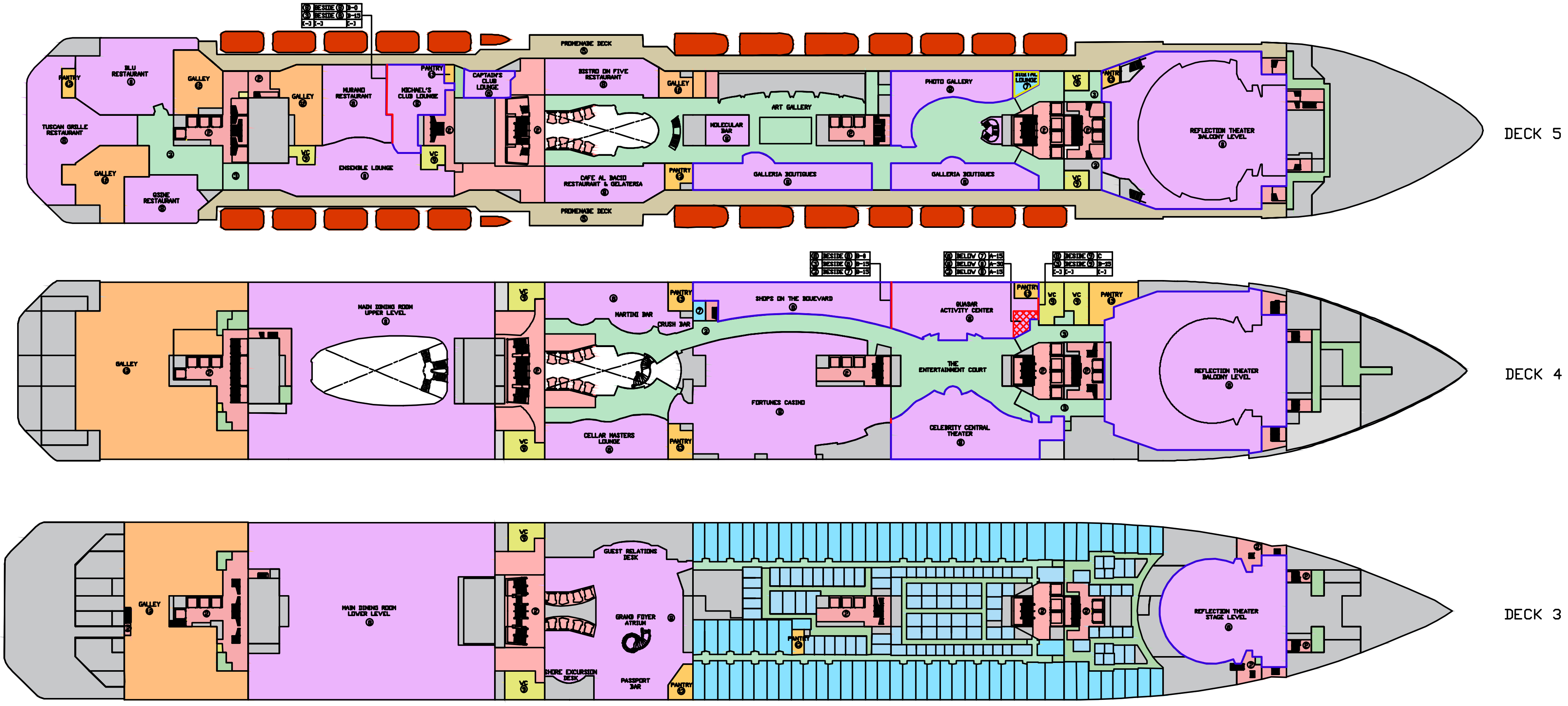
Celebrity Reflection

(blue line)	CONVERSION CASE 1 BOUNDARY
(yellow line)	CONVERSION CASE 2 BOUNDARY
(green line)	CONVERSION CASE 3 BOUNDARY
(red line)	BULKHEAD REQUIRING STRENGTHENING
(red hatching)	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM CURRENT DECK
(red cross-hatching)	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM DECK ABOVE

Example

EXISTING SCENARIO	⑧ BELOW ⑤	A-0	SOLAS STEEL REQUIREMENT
LIKELY SINGE SPACE CONVERSION SCENARIO	⑧ BELOW ⑧	A-30	
LIKELY DOUBLE SPACE CONVERSION SCENARIO	③ BELOW ⑧	A-15	



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STRUCTURAL FIRE PROTECTION
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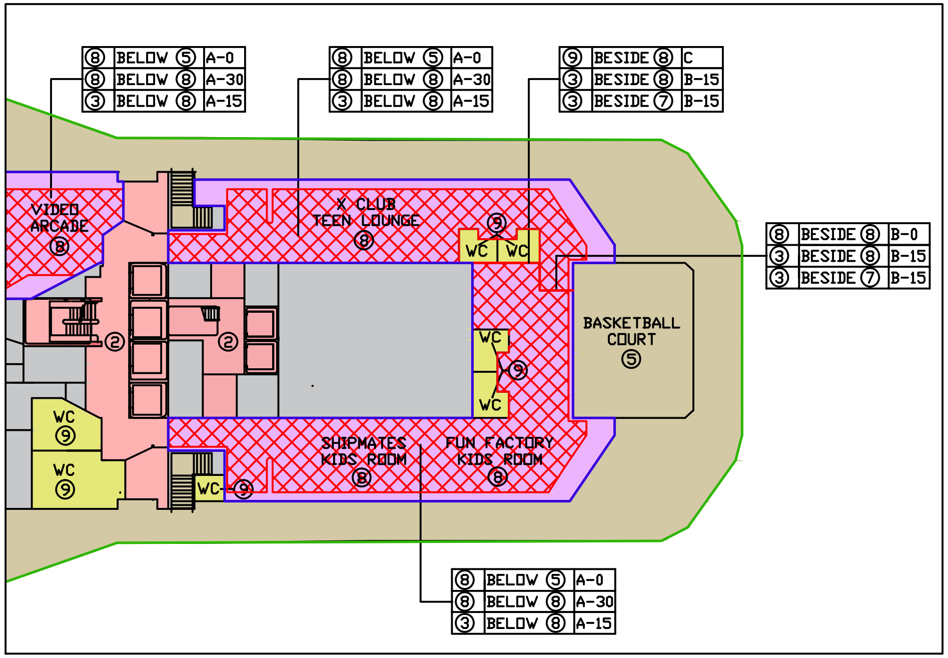
Blue line	CONVERSION CASE 1 BOUNDARY
Yellow line	CONVERSION CASE 2 BOUNDARY
Green line	CONVERSION CASE 3 BOUNDARY
Red line	BULKHEAD REQUIRING STRENGTHENING
Red hatching	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM CURRENT DECK
Red cross-hatching	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM DECK ABOVE

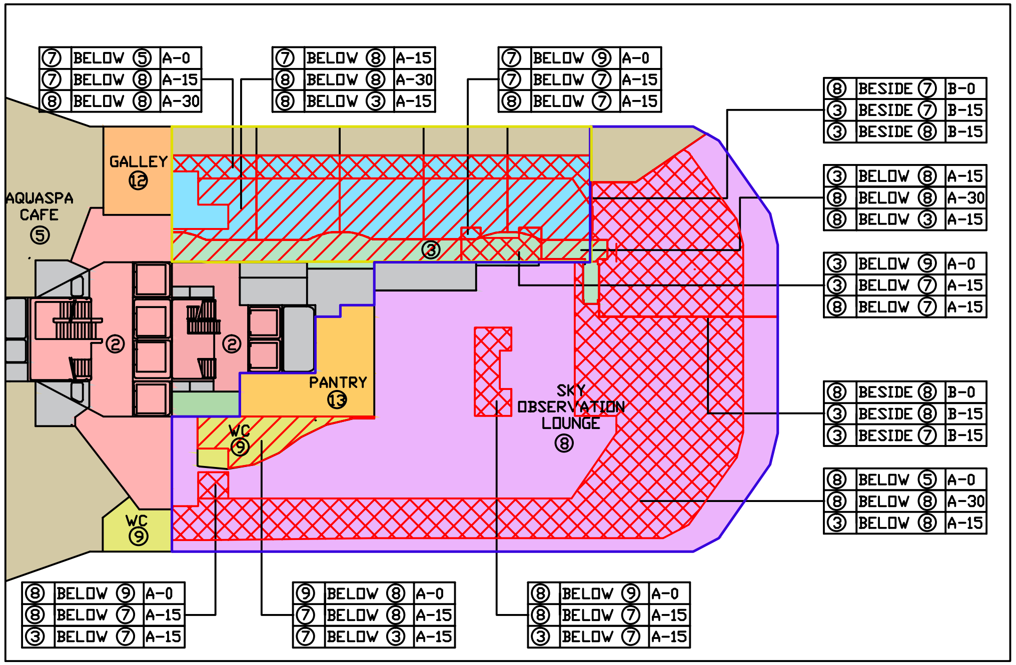
Example

EXISTING SCENARIO	8	BELOW 5	A-0	SOLAS STEEL REQUIREMENT
LIKELY SINGE SPACE CONVERSION SCENARIO	8	BELOW 8	A-30	
LIKELY DOUBLE SPACE CONVERSION SCENARIO	3	BELOW 8	A-15	

DETAIL A



DETAIL B

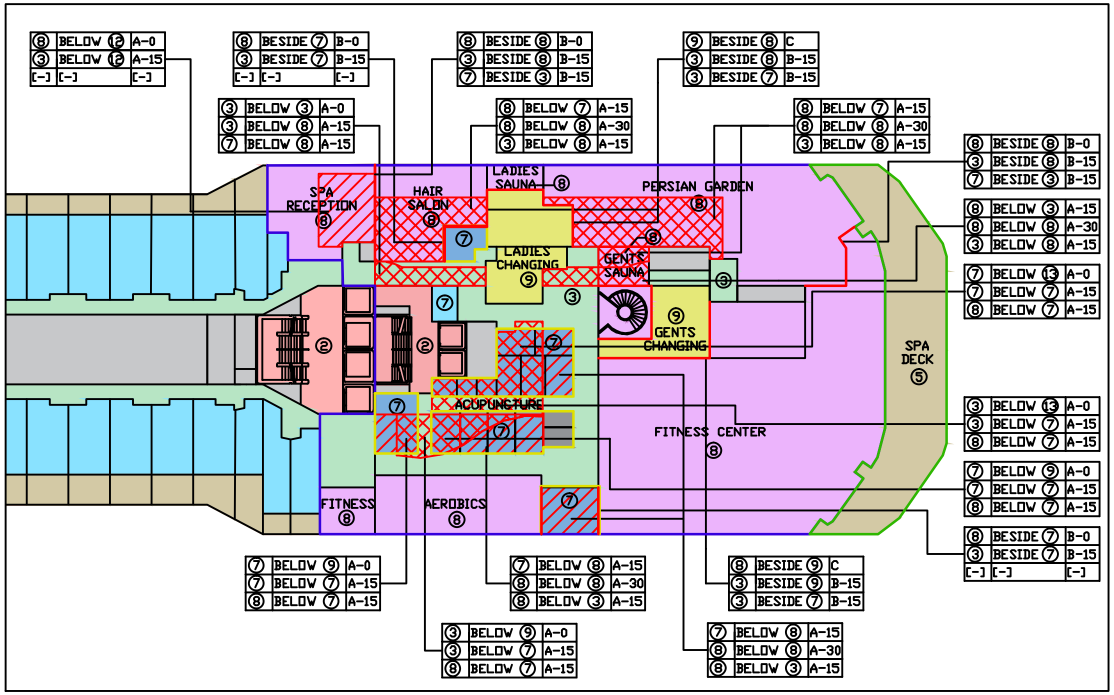


Scale			
NTS	Aalto University School of Engineering	(blue line)	CONVERSION CASE 1 BOUNDARY
Date 28.06.2014		(yellow line)	CONVERSION CASE 2 BOUNDARY
Name JUSTIN CHAMPION	CASE STUDY STRUCTURAL FIRE PROTECTION Celebrity Reflection	(green line)	CONVERSION CASE 3 BOUNDARY
Page 6 Of 7		(red line)	BULKHEAD REQUIRING STRENGTHENING
		(red diagonal hatch)	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM CURRENT DECK
		(red cross hatch)	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM DECK ABOVE

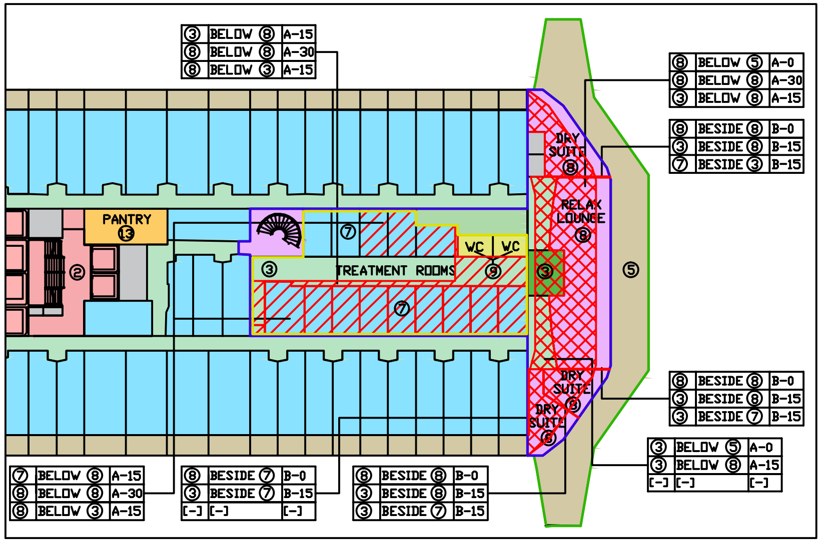
Example

EXISTING SCENARIO	8	BELOW 5	A-0	SOLAS STEEL REQUIREMENT
LIKELY SINGE SPACE CONVERSION SCENARIO	8	BELOW 8	A-30	
LIKELY DOUBLE SPACE CONVERSION SCENARIO	3	BELOW 8	A-15	

DETAIL C



DETAIL D



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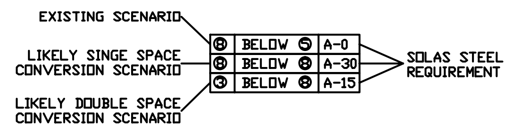
(blue line)	CONVERSION CASE 1 BOUNDARY
(yellow line)	CONVERSION CASE 2 BOUNDARY
(green line)	CONVERSION CASE 3 BOUNDARY
(red line)	BULKHEAD REQUIRING STRENGTHENING
(red hatching)	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM CURRENT DECK
(red cross-hatching)	DECK ABOVE REQUIRING STRENGTHENING DUE TO INFLUENCE FROM DECK ABOVE

Example



Appendix G – Recommendation effectiveness

Table A 19. Potential recommendation effects, *Brilliance of the Seas*

Conversion Task	Description	Conversion Case	Implied Challenges	Potential avoidance?
Lounge reconfiguration	Viking Crown Lounge seperated into smaller, divided spaces	1	minimal due to 30% open spaces	NO
Pool deck enhancement	Movie screen and related structures added	4	weight and stability issues	YES
Lounge conversion	Centrum Lounge converted into winch system equipment room	4	weight and stability issues	YES
Restaurant reclassification	Seaview Cafe converted into Izumi sushi restaurant	0	minimal	NO
Lounge conversion	Country Club and adjacent spaces converted into arcade	2	structural boundary reinforcement	YES
Space reclassification	Arcade converted into Nursery	0	minimal	NO
Open deck conversion	Open Deck converted into Rita's Cantina restaurant	3	structural boundary reinforcement	YES
Lounge conversion	Concierge Club converted into passenger suite	1	minimal - downgraded category	NO
Lounge conversion	Yacht Club converted into passenger cabin	1	minimal - downgraded category	NO
Service space conversion	Bell box galley converted into passenger cabins	1	structural boundary reinforcement	YES
Lounge conversion	Library converted into passenger cabin	1	minimal - downgraded category	NO
Lounge conversion	Explorer's Court converted into passenger cabin	1	minimal - downgraded category	NO
Space reclassification	Bar and lounge converted into pub	0	minimal	NO
Space reclassification	Champagne Bar converted into Vintages bar	0	minimal	NO
Restaurant reclassification	Portofino restaurant converted into Giovanni's Table	0	minimal	NO
Lounge conversion	Card Room converted into Chef's Table dining room	0	minimal	NO
Restaurant conversion	Zephyr Dining Room converted into passenger cabins	1	structural boundary reinforcement	YES

Table A 20. Potential recommendation effects, *Disney Magic*

Conversion Task	Description	Conversion Case	Implied Challenges	Potential avoidance?
Sun deck enhancement	Forward thrill water slide and related structures added	4	weight and stability issues	YES
Pool deck enhancement	Aft water slide added and related structures modified	4	weight and stability issues	YES
Restaurant enlargement	Topsiders buffet extended onto deck space; renamed Cabana's	3	structural boundary reinforcement	YES
WC conversion	WC converted into water slide pump room	0	minimal	NO
Salon enlargement	Beauty Salon extended onto open deck space	3	structural boundary reinforcement	YES
Open deck conversion	Open deck space converted into store rooms and public spaces	3	structural boundary reinforcement	YES
ADA corrections	Existing cabins converted into ADA compliant cabins	0	minimal	NO
Cabin enlargememt	Cabin and adjacent stair space converted into single cabin	2	structural boundary reinforcement	YES
Open deck conversion	Open deck space converted into EDG room	3	structural boundary reinforcement	YES
Space reconfiguration	Kid's facilities seperated into smaller, divided spaces	1	minimal due to 30% open spaces	NO
Space reconfiguration	Nursery and adjacent spaces converted into single nursery space	2	structural boundary reinforcement	YES
Space reclassification	Parrot Cay restaurant refurbished into Carioca's restaurant	0	minimal	NO
Sponson-ducktail addition	Stability enhancement measure	3	weight and stability issues	YES

Table A 21. Potential recommendation effects, *Carnival Sunshine*

Conversion Task	Description	Conversion Case	Implied Challenges	Potential avoidance?
Partial deck addition	Partial decks built and serenity deck areas extended	4	weight and stability issues	YES
Open deck conversion	Open deck space converted into cabin area	3	structural boundary reinforcement	YES
Space conversion	Kid's facilities converted into cabin area	1	structural boundary reinforcement	YES
Serenity deck enhancement	Pool added	4	weight and stability issues	YES
Sun deck enhancement	Mini golf, sports court, and water slides added	4	weight and stability issues	YES
Restaurant conversion	Sun & Sea Restaurant converted into kid's facilities	1	structural boundary reinforcement	YES
Open deck conversion	Open deck space converted into cabin area	3	structural boundary reinforcement	YES
Space conversion	Kid's facilities converted into spa area	0	structural boundary reinforcement	YES
Space conversion	Salon and sauna converted into cabin area	1	structural boundary reinforcement	YES
Space reconfiguration	Spa laout reconfigured	0	minimal	NO
Open deck conversion	Open deck space converted into cabin area	3	structural boundary reinforcement	YES
Pool deck enhancement	Deck bar areas added	4	weight and stability issues	YES
Space reclassification	Deck dining spaces modified	0	minimal	NO
Open deck conversion	Pool deck converted into restaurant spaces	3	structural boundary reinforcement	YES
Space reconfiguration	Casino divided into seperate casino and arcade spaces	1	minimal - downgraded category	NO
Lounge reconfiguration	Point After dance club divided into restaurant and lounge spaces	1	minimal - same categories	NO
Lounge reconfiguration	Criterion Lounge converted into cabin area	1	structural boundary reinforcement	YES
Restaurant conversion	Galaxy dining room upper level converted into seperate spaces	1	structural boundary reinforcement	YES
Lounge reconfiguration	Main theater ground level converted into cabin space	1	structural boundary reinforcement	YES