IMPACT OF SHIP AUTOMATION TECHNOLOGIES ON MERCHANT FLEET COMPETITIVENESS

Harilaos N. Psaraftis
Professor and Head
Department of Naval Architecture and Marine Engineering
National Technical University of Athens
Greece

Invited paper

Presented at the XIV Pan-American Congress of
Naval Engineering, Maritime Transportation and Port Engineering
(XIV COPINAVAL)

June 13-16, 1995
Lima, Peru

Abstract

The merchant fleets of many countries worldwide have experienced a significant decline of competitiveness over the years. Loss of competitiveness is due to the fact that ships in these fleets are generally more expensive to operate than other ships, and shippers prefer the latter because of cost considerations. Such a decline in competitiveness has been manifested in a number of ways. The first has been a net reduction of the number of ships in the fleets plagued by such a problem. A related phenomenon (reflecting essentially the same problem) has been what is known as "flagging out", that is, registering a ship not with the flag of the country of the shipowner, but with another, foreign flag. Such flags, many of which are known as "flags of convenience", allow the shipowner to reduce operating costs by paying lower fees, by being able to hire cheaper crews, and by a variety of other features (such as for instance less stringent regulations on safety, inspection, and maintenance).

Realizing that manning costs are frequently a major percentage of ship operating costs, one of the measures that has been contemplated by many countries in order to help reverse this trend has been the design, development, and operation of highly automated ships manned by reduced crews. The rationale for such a measure is that under appropriate circumstances the savings realized by a reduced payroll could, over the ship's lifetime, offset the additional capital cost of the automated ship, and hence make that ship more competitive than an equivalent conventional ship, even if the latter is manned by a low-salary crew.

The purpose of this paper is to present the results of a cost-benefit analysis that addresses the question to what extent and under which scenarios can such advanced technologies improve merchant fleet competitiveness. The analysis is the product of a European Commission project, and, as such, focuses on the fleets of European Union member states. However, we also attempt to generalize the conclusions to other fleets of the world.

1. Introduction

The merchant fleets of many countries worldwide have experienced a significant decline of competitiveness over the years. Loss of competitiveness is due to the fact that ships in these fleets are generally more expensive to operate than other ships, and shippers prefer the latter because of cost considerations.

Such a decline in competitiveness has been manifested in a number of ways. The first has been a net reduction of the number of ships in the fleets plagued by such a problem. Such has been the fate of many of the fleets of the member states of the European Union (EU)[1], over the years. According to Eurostat (1991), the total EU fleet numbered 11,023 ships in 1980, but only 6,431 ships in 1989. The share of EU fleet as a proportion of the world fleet dropped from 27% to 16% during the same period.
A similar (or sometimes more severe) downward trend has been experienced by other fleets, such as for instance the one of the United States. According to Cuneo (1993), the percentage of US commerce carried on US flag vessels was 42.6% in 1950, dropped to 5.3% in 1970, and was just 4.1% in 1990. The number of US flag ships was 3,408 in 1950, dropped to 1,708 in 1970, and was just 635 ships in 1990.

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[1] In this paper the term EU (European Union) collectively refers to the 12 member states of the European Community *before* the 1995 enlargement, that is: Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and the United Kingdom. The EU was enlarged to 15 member states on 1/1/1995, when Austria, Finland, and Sweden joined.

A related phenomenon (reflecting essentially the same problem) has been what is known as "flagging out", that is, registering a ship not with the flag of the country of the shipowner, but with another, foreign flag. Flags such as Liberia, Panama, Malta, the Bahamas, and Cyprus have been responsible for much of the flagging out that has occurred over the years. Such flags, many of which are known as "flags of convenience" (or "flags of necessity" according to many shipowners) allow the shipowner to reduce operating costs by paying lower fees, by being able to hire cheaper crews (consisting of nationals of other countries), and by a variety of other features (such as for instance less stringent regulations on safety, inspection, and maintenance).

Table 1 illustrates the phenomenon of flagging out for the merchant fleets of EU member states, plus those of the United States and Japan.

Table 1: Flag and controlled fleets of the EU member states, United States, and Japan (ships 1,000 GRT and above; source: Lloyds Register of Shipping, 1992)

COUNTRY	Flag fleet (no. of ships)	Controlled fleet (no. of ships)
Belgium	12	97
Denmark	357	534
Germany	577	1,171
Greece	953	2,561
France	119	200
Italy	565	572
Ireland	52	46
Luxembourg	51	2
Netherlands	415	489
Portugal	40	57
Spain	225	271
United Kingdom	207	735
TOTAL EU	3,573	6,735
United States	469	1021
Japan	1,128	2,835

It can be seen that the total size of the EU flag fleet is about half the size of its controlled fleet. The nations for which flagging out seems to be most acute are Belgium, United Kingdom, Greece, and Germany. Luxembourg, on the other hand, experiences the opposite phenomenon (this is because many Belgium-controlled ships are under Luxembourg's flag). It is noteworthy that the flag and controlled fleets of Spain, the Netherlands, and especially Italy almost coincide. Finally, it can be seen that also the flag fleets of the United States and of Japan are significantly smaller than their controlled fleets.

Realizing that manning costs are frequently a major percentage of ship operating costs, one of the measures that has been contemplated by many countries in order to help reverse this trend has been the design, development, and operation of highly automated ships manned by reduced crews. The rationale for such a measure is that under appropriate circumstances the savings realized by a reduced payroll could, over the ship's lifetime, offset the additional capital cost of the automated ship, and hence make that ship more competitive than an equivalent conventional ship, even if the latter is manned by a low-salary crew.

Numerous "ship of the future" projects have been launched in several countries (e.g, "Schiff der Zukunft" in Germany and "Projekt Skib" in Denmark), with the aim of developing shipboard technologies that would ensure an efficient and safe ship operation while drastically reducing manning onboard the ship. Technologies such as integrated ship control, position fixing devices, satellite navigation, unmanned machinery room, automated cargo handling, automated docking and mooring, voyage management, planned maintenance, fault diagnosis and alarm handling, and others, receive a prominent focus on such ships.

A direct product of "Projekt Skib" was the development, design and subsequent operation of a series of four highly automated reefer ships of 21,680 m^3 (765,650 ft^3) capacity. These ships are owned by Danish shipowner J. Lauritzen A/S. They were designed to be operated by a crew of six, although in actual practice nine crew positions are used. This is indeed a drastic reduction, considering that a conventional vessel of similar size typically has at least 25 crew positions.

The European Commission (Directorate General for Transport -DGVII), realizing the need for applied R&D in this area, sponsored project ATOMOS, within the EURET transport R&D programme of the ATOMOS stands for Advanced Technology to Optimize Manpower Onboard Ships and consists of a consortium of 9 partners from 4 EU countries[2]. The project started in early 1992 and was completed in late 1994. Its scope has been to develop advanced shipboard technologies that would enhance the competitiveness of the fleet of the EU, while maintaining an adequate level of safety.

Describing the entire results of the ATOMOS project (or even those only produced by the team of the National Technical University of Athens- NTUA) is way beyond the scope of this paper. These results are fairly extensive and can be found elsewhere (e.g, in ATOMOS technical reports and other publications). Rather, the purpose of the paper is to present in a concise way the results of the *cost-benefit analysis* of the ATOMOS project. This cost-benefit analysis has been performed by NTUA and aims at investigating the possible impact of ship automation technologies on the competitiveness of the EU fleet.

The rest of the paper is organized as follows. Section 2 outlines the approach used, with an emphasis on the difficulties associated with its implementation. Section 3 presents the sources of data used and comments on their quality. Section 4 presents the results of the cost-benefit analysis. Finally Section 5 presents the conclusions of the paper.

[2] ATOMOS partners: Ferry Division of Danish State Railways (DSB)- (project leader), Danish Maritime Institute, Aalborg University, Logimatic, Danish Maritime Authority, National Technical University of Athens, STN Atlas Elektronik, Lloyds Register of Shipping, and Soeren T. Lyngsoe.

2. Approach

In order to ascertain to what extent and under what conditions the advanced technology systems developed in the ATOMOS project would enhance the competitiveness of the fleet of the European Union (EU), the following kinds questions have to be addressed:

(a) For which ship types, sizes, flags, and economic scenarios (if any), can specific advanced shipboard technologies improve ship competitiveness?

(b) To the extent a competitiveness improvement can be quantified, is this improvement enough to cause a reversal of the documented erosion of the competitiveness of the EU fleet?

In order to answer these questions, a comprehensive cost-benefit analysis is warranted. The methodology behind this analysis is based on the following conceptual approach:

(1) For a given ship, estimate the benefits that can be realized if advanced technology systems are implemented. These benefits mainly concern cost savings due to reduced manpower on board the ship, but may also accrue in some other areas, eg., improved service, reduced maintenance, etc.

(2) For the same ship, estimate the extra costs of this advanced technology. These are mainly the capital costs of purchasing and installing such technology.

(3) Do a straightforward calculation to see if the benefits outweigh the costs. This calculation is based on a comparison of the Required Freight Rate (RFR) of the ship in question to the RFR of an equivalent ship on which the advanced technologies in question have been implemented.

(4) Apply (1) to (3) above to an appropriately defined sample of ships, and draw conclusions for the entire EU fleet (or other fleets as well).

Notice the use of the RFR as the competitiveness criterion. The RFR is the break-even rate for which the Net Present Value (NPV) of the time stream of the differences between revenues and expenses over the lifetime of a ship is zero. This criterion is widely used in comparing maritime transport alternatives. Thus, in comparing ship A of conventional crew and technology with ship B of reduced crew and advanced technology, ship A will be more competitive than ship B if its RFR is lower.

Of course, special care must be taken so that the comparison is meaningful. Notice that RFR is on a $/ton basis and as such provides no information on the scale of the investment. The RFR criterion is likely to favor larger ships due to economies of scale. For this reason, it would not make sense to compare the RFR of a 200,000 ton ship with that of a 20,000 ton ship and claim that the former is more competitive. Section 4 will take care of such difficulties by appropriately defining the framework for comparison. Additional competitiveness criteria can be found in Psaraftis et al (1992).

In spite of the apparent simplicity of the approach (1) to (4) above, the actual implementation of such a methodology is by no means easy. This is true for the following reasons:

Difficulty 1: The amount of data necessary for doing a comprehensive analysis along the above lines is extremely large.

This can be first understood by the fact that performing a comprehensive analysis *even for a single ship* would entail collecting data on variables such as those displayed in Table 2:

Table 2: Variables impacted by crew reduction due to advanced technology

Variables impacted directly	Variables impacted indirectly
-crew size, composition, wages, total payroll -other crew expenses (victualling, travel, overtime, pensions, other compensation, etc) -cost of crew training for new technologies -cost of purchase/installation of advanced equipment	- wages of extra shore personnel who might be hired for some tasks - cost of ship construction (bridge, accommodation, etc) - cost of purchase/installation of crew rescue equipment (boats, rafts, etc) - cost of ship maintenance - cost of bunkers - cost of loading/unloading - cost of insurance - cost of probable accidents - cost of ship down-time - demand for the ship because of improved service - freight rate that can be charged by ship because of improved service - etc

Of course, the line between these two categories is to some extent arbitrary: for instance, one could consider the cost of crew training as an indirect variable. Also, the second category (indirect variables) is in reality open-ended.

To make things worse, if collecting all such data for a single ship is non-trivial, performing such an analysis so that meaningful results can be obtained for the whole spectrum of different ship types, sizes, and flags of the EU, would multiply the necessary data collection effort by a few orders of magnitude.

Difficulty 2: Some of the necessary data are difficult to collect, may be incomplete, or sometimes simply nonexistent.

That this is particularly true for most of the variables that fall under the "indirect" label (see above) was to be expected. In the course of data collection however, we realized that this was also true for the other class also, for a variety of reasons. For instance,

-many shipping companies are reluctant to divulge cost information
-many shipping companies do not have the time to respond to detailed cost questionnaires
-collected data is of non-uniform composition and quality
-some of the technologies (particularly those developed under ATOMOS) are so new, that no reliable data on their cost-effectiveness exists.

Difficulty 3: Calculating some components of the cost- benefit equation was outside the scope of the ATOMOS project.

One example of this (and not the only one) is the calculation of the expected economic benefits due to a fault diagnosis and alarm handling system. To calculate such benefits one would have to calculate how much the probability of an accident is reduced by such a system, and, how much monetary damage such a system would avert.

The nature of the limitations outlined above has shaped, to a significant extent, the way in which the methodology is to be applied. This will be described in Section 4. Before that, Section 3 outlines the various data categories, and comments on the quality of the data obtained.

3. Sources and quality of data

A extensive amount of effort was spent by the NTUA research team in collecting the data that was deemed necessary to perform the analysis. Data can be classified into the following major categories:

a) Fleet data: Per agreement with ATOMOS partner Lloyds Register of Shipping (LRS), we obtained detailed data for 25,058 ships. These are all major types of commercial ships in the world over 1,000 GRT, as of 1992. The LRS database has 78 fields of information for each ship, describing all major ship characteristics, including technological level and crew size.

The quality of this dataset is excellent, except in those parts of it that contain information that is not uniformly available for all ships. The latter mainly concerns data on various technological features of the ship. For example, unattended machinery space, centralized control, etc. are only recorded for LR-classed vessels. Also, crew size information is of non-uniform quality, being available for some ships and unavailable for others. So this dataset is not 100% perfect, for many ships do not have information for all data fields. Still, we would rate it as one of good quality overall. It has been useful in our search for more detailed information (questionnaires) and for some of the fleet analyses that will be presented in Section 4.

b) Manning cost data: Seafarer organizations' collective labor agreements were one of the sources. We obtained such detailed information for Greece, Germany, Italy, the Netherlands, Denmark (including its international register DIS) and Portugal. The United Kingdom replied that all wages are freely negotiable, and the same is true for Ireland. We also have collective labor agreement wage information for some countries outside the EU, such as Japan, the Philippines, and the collective labor agreement of the International Transport workers Federation (ITF). Of course, collective labor agreements provide only guidelines for minimum allowable wages, but in the cost benefit analysis we shall take this into account.

A second source for manning costs has been the result of a questionnaire on ship costs (including manning) produced by NTUA and sent to about 800 shipping companies worldwide. In spite of a confidentiality pledge, only 78 ships, representing 9 flags (of which only 3 flags were EU flags- Greece, Italy, and Portugal) have returned this questionnaire. Other flags were Cyprus, Hong Kong, Liberia, Malta, and Panama. This yield is not impressive, however the sample includes also other cost data, and the data of other flags is useful for a comparison of competitiveness.

A third source of manning costs is from previously published external reports, all in the public domain. Psaraftis et al (1994a) gives more details on these sources. Here we state that from these sources we obtained crew cost data for at least the following flags: The Netherlands, Spain (including Canary Islands), Norway, (including its international register NIS), United Kingdom, United States, Bahamas, Liberia, Australia, and various undisclosed European and Asian flags.

Finally, we got actual wage data from DSB (the ATOMOS project leader) and from various Greek companies by interview.

In summary, we consider our yield on manning cost data to be of acceptable breadth, depth, and quality.

c) Other ship running cost data: Here we obtained a heterogeneous variety of other costs from various sources, including our own questionnaires, and data from other reports. The purpose of collecting such other cost data is to get a broader picture of ship operating costs.

Although the amount of collected data in this category is not small, the overall quality and therefore usefulness of such data is not as high as we would have liked. Psaraftis et al (1994a) provides more detail about what can be learned from this data.

d) Ship capital cost data: From H.P Drewry publications we collected ship purchase price information for several thousand transactions over the last few years. This includes newbuildings, secondhand ships, and ships sold for scrap. The quality of this information is non-uniform, being excellent for specific cases (e.g., secondhand tankers and bulk carriers) and not so rich in other cases (new containerships).

e) Advanced technology data: A significant amount of effort was devoted to soliciting data on the costs and benefits of shipboard advance technologies that are the object of ATOMOS. This effort involved questionnaire solicitations from other ATOMOS partners and equipment vendors, a specialized workshop, a second questionnaire targeted to owners of "high-tech" ships, and a literature search. The purpose of such an effort was to determine the potential economic savings in manpower (crew size, manhours) that advanced shipboard technologies would realize, and the cost at which such savings would be possible. Psaraftis et al (1994a) describes this part of our work in detail.

The overall result of this effort can be rated as less informative than desired. Although we did manage to collect some relevant data that allow us to make some points on the above general subject, we feel that a lot more data is needed in order to make more global and concrete conclusions. Unfortunately, and to the best of our knowledge, most of this data is simply non-existent today. This is particularly true for data on the systems still under development, as experience on the cost of these systems as well as their effectiveness is still years away.

f) Miscellaneous other data: We finally collected a variety of other data, such as national legislations on crew composition, data on main trade routes, data on port dues, exchange rate data (to convert all costs in a common currency- which we have assumed to be 1992 US Dollars), inflation data, and interest rate data. We assess the overall quality of this other data as acceptable.

4. Cost-benefit analysis

4.1 Overview

Due to reasons dealing mainly with the quality of data collected as outlined earlier, it was decided that our cost-benefit analysis methodology be structured into three hierarchical levels: I, II, and III, defined as follows:

Level I analyzes only one ship, and aims at illustrating, by means of a detailed example, the procedure one should follow to assess the competitiveness improvement resulting from the implementation of advanced technologies onboard that ship. It should be emphasized that since the full application of this procedure requires certain assumptions for those parts of the data that is not directly available (or is simply unknown), and, since only one ship is examined, obviously no conclusions on any competitiveness issue can be drawn from Level I alone.

Rather, the main purpose of the Level I analysis is to present the full cost-benefit analysis methodology that should be followed if or when all relevant data is available for a given ship. A secondary purpose of this analysis is to identify the various categories of data that should be available in order to carry out such an analysis.

Level II analyzes these ships for which manning and other cost data has been collected by means of the cost questionnaire. Such a questionnaire was sent to about 800 shipping companies worldwide. Responses were collected for 78 ships, covering a broad spectrum of ship types.

Of these 78 ships, only 47 have relatively accurate crew composition information (particularly on the breakdown into officers and ratings and on information on their nationalities, which is important). Of these 47 ships, only 20 are EU-flagged, representing only three (3) EU flags, those of Greece (16 ships), Italy (1 ship), and Portugal (3 ships). Eight (8) major ship types are represented.

So the Level II analysis deals only with these 20 ships, and carries out the following:

a) a comparison of each of these ships' required freight rate (RFR's) with the RFR of a hypothetical but "equivalent" reduced-crew (ATOMOS) ship that has a crew consisting of flag nationals. Two ATOMOS configurations are examined, one in which the crew is 15, and one in which it is 10 persons.

b) a comparison of the RFR of each of these ships (and, by extension, of the RFR's of the equivalent ATOMOS ships) with the RFR of a hypothetical but equivalent "cheap crew" ship flying a flag of convenience.

c) a calculation of how much extra initial capital cost the shipowner of the each of these ships would be willing to pay in order to own an ATOMOS-type ship instead of a conventional one.

d) a sensitivity analysis of results with respect to some of the parameters of the analysis.

Due to the sample size limitations of the Level II analysis, again no global conclusions from it can be drawn. However, certain interesting observations and trends have been obtained. These, together with the analysis of Level III can be used to draw some more general conclusions.

Finally, **Level III** draws from the entire LRS world ship database (25,058 ships), as well as from additional crew wage information obtained for several crew nationalities. The sample size of the Level III analysis is 1,487 ships, which are all ships for which:

i) the LRS database has crew size and BHP information,
ii) the crew is 11 or above, and
iii) the flag is one of the 12 EU states (as defined earlier), or of Norway, Sweden, Finland, Japan, or the United States.

Level III analysis is carried out for these 1,487 ships, and, in the absence of additional information, is strictly limited to manning cost considerations, and at a fairly aggregate level at that. After some assumptions, it compares the *estimated* manning cost of each of these ships with the estimated manning cost of:

a) a hypothetical equivalent ATOMOS-type ship (of crew size 10) manned by flag nationals, and with

b) a hypothetical equivalent "cheap crew" conventional ship that flies the same flag with the parent ship, and for which only the captain and the first officer are flag nationals and the rest of the crew are low-salaried non-EU nationals.

It should be mentioned that even though alternative (b) above may be illegal from the standpoint of many current national manning legislations in the EU and elsewhere (e.g., the US), Level III examines it as a "what if" prelegislative scenario that might (under certain circumstances) be viewed as a policy alternative to reduced manning in some countries.

From these comparisons, an estimate of the amount the shipowner of each of these ships would be willing to pay to have an ATOMOS-type ship instead of a conventional one can be made (based only on manning cost differentials). Also, a competitiveness comparison between the above two alternatives is made, and the ship types and flags for which alternative (a) is better than alternative (b) are identified.

The trends identified in the Level III analysis support some more general conclusions for the ATOMOS project.

With these preliminary considerations, Sections 4.2, 4.3, and 4.4 present the analyses of levels I, II, and III (respectively) in some detail.

4.2 Level I analysis

The purpose of the Level I analysis is to explain, by means of a detailed example, the procedure one should follow to assess the competitiveness improvement resulting from the implementation of specific advanced technologies. This analysis is carried out for a ship for which the cost data collected is reasonably complete. Even for this ship, however, not all desirable data is available, so certain assumptions have to be made.

The analyzed ship will remain unidentified for reasons of confidentiality. It is a 1992 newbuilding gas carrier, flying the Italian flag. The ship has a payload of 5,800 tons and follows a worldwide route, making an average of 25 voyages per year. It has a crew of 19 (7 officers and 12 ratings). Its purchase price has been USD50 million[3]; USD32 million were the down payment and the remaining USD18 million were financed by a 15-year loan with a yearly interest rate of 13%. The total yearly costs (including loan repayment) are USD4,138,128.

The RFR is given by the following equation:

$$\sum_{t=0}^{N} (RFR*X_t-C_t)/(1+i)^t = 0$$

where C_t is the total cost at year t (C_0 being the down payment on the purchase price), X_t is the payload at year t, N is the lifetime of the ship (here we assume it is 20 years), and i is the real cost of capital, or real discount rate (by "real" we mean that it is the difference of the nominal rate minus inflation).

For the ship under consideration, the data provided gives that C_0 = USD32 million and C_1 = USD4,138,128. We will calculate the RFR for various values of X_1 and i. Since the ship makes an average of 25 voyages a year, the suggested values for X_1 arise by multiplying 25 by 50%, 75%, or 100% of the payload (5,800 tons). By taking thus various combinations of values for the parameters

[3] 1992 US dollars are used throughout this paper.

whose values cannot be precisely fixed, we will be able to ascertain the sensitivity of our conclusions to these uncertainties in the data.

Table 3: RFR (in USD/ton) for various values of X_1 and i.

X_1	i = 2%	i = 5%	i = 10%	i = 15%	i = 20%	i = 25%
72,500 t	79.2	85.6	97.5	110.0	122.6	134.7
108,750 t	59.4	64.2	73.1	82.5	91.9	101.0
145,000 t	39.6	42.8	48.7	55.0	61.3	67.3

It can be seen from the above table that the RFR is quite sensitive to the payload X_1, while it is less sensitive to the value of i. As expected, RFR increases when i increases or when X_1 decreases.

The main part of the Level I analysis deals with the computation of the competitiveness improvement that would result from the implementation of three (3) advanced technologies in the ship under consideration. The three advanced technologies to be considered are: integrated ship control, position fixing devices, and automated mooring system. These technologies are selected because data for them happens to be available from other ships in which they are implemented (questionnaire on high-tech ships). As data for these technologies is not available for the specific ship under study, this might raise the question to what extent this data can be used here. It should be clear, however, that the purpose of the Level I analysis is not to reach conclusions on any specific ship or technology; the purpose is rather to illustrate the way in which competitiveness improvement would be calculated if all necessary data were available for a specific ship.

For each of the technologies mentioned above, a fictitious ship, equivalent to the original ship is considered. This new ship differs from the original ship only in that it has the specific advanced technology implemented. Therefore, the costs of the two ships will be identical for all categories, except for those categories which are affected by the advanced technology in question. For instance, integrated ship control will eliminate some crew positions, so that the manning costs of the new ship will be lower than the manning costs of the original ship. Which cost categories will be affected will of course depend on the specific advanced technology under consideration. One cost category that is always affected is the capital cost, since the capital cost of the new ship exceeds the capital cost of the original ship by an amount equal to the cost of the advanced technology.

Having thus defined the new ship, the RFR of this new ship will be calculated and compared to the RFR of the original ship. Since the two ships only differ in that the one has the advanced technology while the other does not have it, any difference in the RFR can only be the effect of the advanced technology. Specifically, if the RFR of the new ship is lower than the RFR of the original ship, the conclusion will be that the advanced technology improves competitiveness, and the difference between the two RFRs will be a measure of how much competitiveness is improved. Similarly, if the RFR of the new ship is higher than the RFR of the original ship, the conclusion will be that the advanced technology is unprofitable (presumably because its cost is higher than the benefits derived from it).

For illustration purposes (and due to space limitations) in this paper we only present the analysis for an integrated ship control (ISC) system.

From data collected through questionnaires, the cost of an ISC system is estimated at about USD1 million. We assume, for the sake of simplicity, that this cost increases the down payment C_0 from USD32 million to USD33 million. ISC is expected to affect manning costs directly, by the elimination of some crew positions, and maintenance costs indirectly. Since data is not available on the effect of integrated ship control on maintenance and repairs, the corresponding effect will be considered negligible for the purposes of this analysis. On the other hand, from the questionnaires it follows that two officer positions are eliminated (out of 7). After some straightforward calculations, the yearly cost C_1 for the new ship is USD4,022,136.

Table 4: Differences (USD/ton,%) RFR of original ship minus RFR of ship with ISC.

X_1	i = 2%	i = 5%	i = 10%	i = 15%	i = 20%	i = 25%
72,500 t	.7 (.9%)	.4 (.5%)	.0 (.0%)	-.5 (-.5%)	-1. (-.8%)	-1.5 (-1.1%)
108,750 t	.5 (.8%)	.3 (.5%)	.0 (.0%)	-.4 (-.5%)	-.8 (-.9%)	-1.1 (-1.1%)
145,000 t	.3 (.8%)	.2 (.5%)	.0 (.0%)	-.3 (-.5%)	-.5 (-.8%)	-.8 (-1.2%)

Table 4 gives the differences (RFR of the original ship - RFR of ship with ISC). It can be seen that the differences are sometimes positive and sometimes negative, depending on the rate i. In fact, differences are positive (competitiveness improvement) for small i but become negative for large i. If we compare the two ships, we see that in the new ship we make an additional initial investment of USD1 million (cost of integrated ship control) and we save a series of 20 yearly cash flows of USD115,992 each (savings in manning costs). The present value of this series of cash flows, which represents the savings achieved by the new technology, decreases as i increases, and eventually becomes, for large i, smaller than the initial investment of USD1 million. These results hold regardless of the payload.

This result points to the importance of the value of i, the real cost of capital, in determining the cost-effectiveness of a specific technology. It means that the same technology may improve the competitiveness of a ship for certain values of i, or reduce it for other values. In general, low values of i are more favorable to such technologies than higher values of i.

A second remark on this example is that the differences in RFR are always negligible, never exceeding 1.5% when expressed as percentages of the RFR of the original ship. Nevertheless, the cumulative effect of a great number of advanced technologies may still turn out to be non-negligible.

It is straightforward to extend this analysis to other advanced technologies. The analysis in Psaraftis et al (1994b) does so for the other two advanced technologies described above, such as position fixing devices and automated mooring. Other cases can also be examined. In each case, the extra cost of the specific technology would be compared to the net present value of the savings in manning cost over the ship's lifetime. If the latter exceeds the former, the technology in question would increase the ship's competitiveness.

Equally straightforward would be an extension of this method in case a technology causes some indirect economic benefits (in addition to reduced manning costs). For instance, an automated mooring system, in addition to saving manning costs, could also reduce port time. This would translate into more trips per year, more payload carried per year, and hence a reduced RFR. An automated planned maintenance system could result in less maintenance costs, leading again to a reduced RFR. And so on. Any of these economic benefits can be taken into account easily, so long as they can be quantified (which is the difficulty that is typically encountered).

Less straightforward would be an extension of this model in order to translate into economic terms a possible improvement of the overall safety or reliability of the ship (because of the advanced technologies), and the possible increase in service quality as a result. One common difficulty of such an analysis is the quantification of benefits that accrue because of improved safety features.

As noted in the beginning, no conclusions from the Level I analysis can be drawn. To draw some conclusions, one has to proceed to Levels II and III.

4.3 Level II analysis

By contrast to Level I, which needs data on the cost-effectiveness of specific shipboard technologies in order to calculate whether a reduced-crew ship is more competitive than an equivalent conventional one, in Level II (as well as in Level III) no such information is provided. In fact, such information is not necessary to do the analysis, since much of the analysis itself is done "in reverse." Instead of asking the question whether specific technologies increase the competitiveness of a ship if installed on it, we ask the question what would be the maximum additional capital cost a shipowner would be willing to pay in order to have an "ATOMOS-type" ship instead of the conventional ship he owns.

In order to answer this question, we have to calculate the operating cost differentials between each of the (real) 20 ships of the Level II sample and an "ATOMOS-type" ship, appropriately defined, and calculate the net present value of the time-series of these differentials, over the ship's lifetime.

The Level II approach has to make some assumptions about what one means by the term "ATOMOS-type ship." We first assume that the latter is a hypothetical, but equivalent ship to the parent (conventional) one, equivalence being defined in terms of payload and speed (so that the comparison is valid).

In Level II two cases are examined. In the first one the ATOMOS-type ship has a crew of 15 (8 officers and 7 ratings), and in the second one it has a crew of 10 (6 officers and 4 ratings). Both cases represent fairly realistic crew sizes in terms of the technologies that are available (the 10-man ship closely resembling the configuration of the Lauritzen automated reefers). We chose to deliberately not examine even smaller crews (such as 6, for instance), because of the uncertainty surrounding the possible performance of such a drastically small crew in emergency situations. Nevertheless, the user may, at his own option, examine such crews if he would like to investigate such an alternative.

Note that both cases assume that crew size and composition for an ATOMOS-type ship are constant (8+7 or 6+4), independent of parent ship type and size. This is a considerable simplification, for it ignores possible differentiations that may result in a different size and composition of an ATOMOS-type ship (for instance, for a very small parent ship, one that has a small original crew, the equivalent ATOMOS-type ship may have a crew of less than 10 people). From the data we had at our disposal, it was impossible to come up with an ATOMOS-type ship crew composition that was a function of all these parameters, and decided to adopt the simpler configurations described above.

Another assumption is that an ATOMOS-type ship is manned only by flag nationals. In particular, we do not examine the scenario of manning such ships with cheap crews that are found in ships flying flags of convenience. Although a ship that is both cheap-crew and highly automated (reduced-crew) is not an impossibility, it is plausible to assume that the skills required to operate such a ship would likely preclude low-skilled, low-salaried marine labor.

[We note here parenthetically that such an assumption is potentially dangerous, as the ability of Southeastern Asian nations to produce highly sophisticated industrial products using cheap labor has shown, to the detriment of various Western industries worldwide. A cheap-crew, reduced-crew, highly automated ship would be a formidable competitor for EU flag ships. Perhaps because the competitiveness of such a ship (at least in terms of cost) would always be higher than that of an equivalent EU ship, we thought that examining such a comparison here would not be that interesting].

By contrast, we definitely wish to compare an ATOMOS-type ship not only with its parent ship, but also with an equivalent conventional ship manned with a cheap crew. We do so because it is the latter type of ship that is mainly responsible for the loss in competitiveness in ships flying EU and other flags (e.g, US) and for the flagging out that has occurred for these flags over the years. As the very concept of a reduced-crew ship has been born in order to mainly counter the effect of cheap-crew ships, a comparison between these two types of ships would be important.

The comparison is made in terms of RFR, the required freight rate, and involves four (4) ships for each ship out of the 20 ships that are the objects of the Level II analysis:

a) the real ship itself (parent ship),
b) a hypothetical equivalent 15-man ATOMOS-type ship,
c) a hypothetical equivalent 10-man ATOMOS-type ship, and
d) a hypothetical equivalent conventional cheap-crew ship.

Several clarifications are in order:

1) ATOMOS-type ships are manned only by nationals of the flag of the parent ship, even if the parent ship is not universally manned by flag nationals.

2) For the ATOMOS-type ships, all the technologies implemented, as well as the design of the ISC system are considered here as a "black box." The only "bottom line" difference between these ships is that an ATOMOS-type ship has a reduced crew of size either 15 or 10, everything else (i.e., operating costs other than manning) being equal.

3) Each cheap-crew ship has a crew size equal to that of a parent ship, but of different nationality, and it flies a different flag. As above, the only "bottom line" difference between these ships is that a cheap-crew ship has a crew that is paid significantly less than the parent ship crew, everything else (i.e., operating costs other than manning) being equal.

4) The individual salary level (including bonuses, benefits, and pension contributions) for the ATOMOS-type ships is assumed to be the average salary of the specific nationality of crew class (officers or ratings), as that has been collected from the ATOMOS ship cost questionnaires. This salary is not necessarily equal to the official salary as specified by a collective labor agreement.

5) The individual salary level (including bonuses, benefits, and pension contributions) for the cheap-crew ships is assumed to be the cheapest among non-EU flags that was collected from the 78 collected ATOMOS ship cost questionnaires. That was found in a Cypriot-flagged ship, and runs at USD 21,719/year for each officer, and USD 12,731/year for each rating on the average (1992 USD).

6) For each ship, several alternative trade routes are examined, depending on ship type. For instance, for the 20,676 GRT Greek bulk carrier (having a crew of 26), the routes Fremantle-Portland (1,484 nautical miles), Calcutta-Durban (4,735 nm), and Melbourne-Gibraltar (9,810 nm) are examined. Databases incorporating all relevant port dues and bunker prices have also been created.

7) A default capacity utilization of 80% is assumed on the average for each ship, with the economic life being 25 years.

8) Voyage costs have been calculated by estimating the fuel consumptions for main engine and generators for those ships that did not provide this information explicitly because they were on term charter.

9) Loan conditions for buying a ship are: 20% down payment, 80% loan, loan rate 3%, 6%, and 12%, payback period 15 years.

10) For the RFR calculations, the shipowner's real cost of capital (real discount rate) is assumed to range from 0% to 10%. "Real" means that this is the difference between the nominal rate and inflation. As Level I has shown, this is a very important parameter, with a low value generally favoring ATOMOS-type ships and a high value favoring conventional ships (parent and cheap-crew ones).

11) None of the 20 ships of the Level II analysis has multiple (rotating) crews. If a ship (for instance a ferry) has more than one crews (to provide, for instance, 24-hr service), the total manning cost is a multiple of the cost of a single crew, and that has to be taken into account.

We now look at the Level II results and their implications. To simplify notation, we denote as ATOMOS-N (N=15 or 10) the ATOMOS-type ship that has a crew of N people.

The first result has been that for all 20 ships, an ATOMOS-type ship is cheaper to run than the parent ship. This is so even though some of the parent ships are not uniformly manned with all-EU crews, while ATOMOS ships are manned by EU (flag) nationals (by definition). Of course, greater savings are realized for an ATOMOS-10 ship than for an ATOMOS-15 ship. The savings for the former range from 42% to 65% of total manning cost, while for the latter they range from 12% to 45% of total manning cost.

If this is the good news, there is also some bad news: the savings in manning cost for a cheap-crew ship (as defined earlier) can sometimes be greater than the ATOMOS savings (although not always greater). Indeed, these savings can be as high as about 70% of total manning cost if a cheap crew is used instead of the original one. And if one adds the fact that an ATOMOS-type ship is more expensive (which is not taken into account so far), this shows that whereas an ATOMOS-type ship is more competitive than a conventional ship, sometimes a cheap-crew ship can be even more competitive (at least on cost).

Looking again at these results, of the 20 ships, an ATOMOS-10 ship is cheaper to man than a cheap-crew ship in 11 cases (and another case is almost a tie), whereas an ATOMOS-15 ship is cheaper to man than a cheap-crew ship in only 3 cases, with another 2 cases being virtually tied. These rankings do not automatically translate into competitiveness rankings, for they ignore the fact that the ATOMOS-ships are more expensive to acquire. If the latter is taken into account, then it is very likely that no ATOMOS-15 ship will be able to compete (on an RFR basis) with its equivalent cheap-crew ship, whereas less than half of the ATOMOS-10 ships will be able to do so.

This result leads us to the following conjecture (a conjecture is a plausible hypothesis which is supported by some evidence like the one presented above, but, because the evidence is mainly circumstantial due to small sample, one cannot use it as a global conclusion):

Conjecture No. 1: Although an ATOMOS-type ship with a crew of 15 would realize some savings in manning cost, such a ship is not likely to be able to beat conventional cheap-crew non-EU flag competition (at least on cost). An ATOMOS-type ship with a crew of 10 would have more chances to do so, under certain circumstances.

Figure 1 shows some typical RFR's for 3 Greek dry cargo ships as a function of the route distance.

Notice that even though all 3 ships have similar sizes and identical crew sizes (23), their manning costs are different. Three routes are assumed, of distances 1007, 4598, and 11223 nm. One can notice that in all 3 ships the ATOMOS-15 ship has a higher RFR (is less competitive) than the cheap-crew ship, but in two of the ships the ATOMOS-10 ship has a lower RFR (is more competitive) than the cheap-crew ship. These results hold irrespective of route. A i=0% real cost of capital is assumed in these runs, meaning that the nominal cost of capital is equal to the inflation rate.

Figure 1: Typical RFR's for 3 Greek dry cargo ships as a function of the route distance.

Even though the value of i is important (as shown in Level I), here since no capital cost differential is assumed between equivalent ships, these RFR rankings will not change if the real cost of capital is changed (as much as the values of the RFR's will change). Of course, the value of i will be important when we examine the issue of how much more a shipowner is willing to pay to acquire an ATOMOS-type ship.

Some additional insights into which, among the ATOMOS-type ships of this sample, are likely to remain competitive with the cheap-crew ships are provided by Figure 2, which ranks all 20 ships by increasing order of ratio "ATOMOS-10 RFR / cheap-crew RFR." Notice that most (not all) Greek-flagged ships have this ratio below 1.0, while all Portuguese and (most notably) Italian -flagged ships have this ratio clearly above 1.0.

Figure 2: Ranking of 20 ships by increasing order of ratio ATOMOS-10 RFR / cheap-crew RFR.

The main difference among these 3 flags being average crew salary level (with Greek-flagged ships being the cheapest, and Italian-flagged ship being the most expensive of the three flags), the following can be conjectured:

Conjecture No. 2: ATOMOS technologies have the greatest chance of beating conventional cheap-crew non-EU flag competition if implemented on EU ships that have the lowest average salary level.

Although ATOMOS ships were assumed to be manned by flag nationals here, we note that average salary level depends not only on salaries paid to flag nationals, but also (and perhaps more important) on what are the allowable other nationalities that can man a ship. In that sense, Conjecture No. 2 seems perhaps a counter-intuitive result, since conventional wisdom would probably point the other way: that ATOMOS technologies can mainly benefit EU ships that are manned by *expensive* crews. After all, it is mainly in fleets of countries such as Denmark and Germany (and US and Japan outside the EU) and much less in (say) the Greek fleet that ship automation technologies can be found these days. In addition, much of the interest for ATOMOS-type ships and technologies can be found in expensive-crew countries, and much less in others. So how can Conjecture No. 2 be reconciled with this fact? Is it, in fact, a valid conjecture?

Before any further discussion of this issue, let us present some additional results. For each of the 20 ships, Figure 3 shows the maximum additional capital cost a shipowner would be willing to pay in order to have an ATOMOS-type ship instead of a conventional one. By definition, this is the NPV of the time stream of annual manning cost differentials, over the lifetime of the ship (taken here to be 25 years). The crew size of each parent ship is also displayed in the Figure (square dot and scale on the right hand side).

Figure 3:
Maximum additional capital cost a shipowner would be willing to pay in order to have an ATOMOS-type ship instead of a conventional one.

This NPV is a decreasing function of i, the real cost of capital. Figure 3 assumes i=0%, which means that NPV equals 25 times the annual cost differential, the maximum possible. By contrast, if i=10%, NPV equals only 9.08 times the annual cost differential (all bars in the histograms would be scaled down proportionately in both cases). This trend shows that a low i favors ATOMOS-type ships while a high i does the opposite, so i=0% is clearly the most favorable case for ATOMOS-type ships.

To interpret these results, we recall that from two independent sources (a specialized ATOMOS project workshop, and an MIT report (Marcus and Weber, 1994)), the estimated cost of an ATOMOS "package" is about one million USD, whereas data from our own ATOMOS high-tech ship questionnaire, an estimate of 2 million USD was given. Since almost all NPV's in the histograms of Figure 3 are above the 2 million figure, this means that, *if i=0%,* an ATOMOS-type ship is a profitable proposition in almost all cases displayed.

It is interesting to observe that of the 6 most profitable cases (in absolute terms) 2 ships are Portuguese and one Italian, while of the 13 least profitable, 12 are Greek. Although one might be tempted to conjecture here that, in absolute terms, most profitable investments in ATOMOS-type technologies are in EU flags that are more expensive than others, we shall refrain from doing so before we examine a larger sample of ships (Level III analysis).

Things get less favorable for ATOMOS-type technologies if i, the cost of capital, is increased. If i=10%, 9 of the 20 ships have an NPV less than 1 million USD for an ATOMOS-15 ship, although none of the ships do so for an ATOMOS-10 ship. This is to be expected, as a high discount rate makes future savings on manning cost less important, while the shipowner has to pay the additional capital cost of the advanced technologies upfront.

Before we move on to Level III, we come back to Conjecture No. 2, that is, that "ATOMOS technologies have the greatest chance of beating conventional cheap-crew non-EU flag competition if implemented on EU ships that have the lowest average salary level." We believe that even if "in absolute terms, most profitable investments in ATOMOS-type technologies are in EU flags that are more expensive than others," Conjecture No. 2 is valid. Consider an oversimplified example:

Suppose that two identical and conventional ships, one manned by a relatively high-salary crew (say, flying the German flag), and one manned by a relatively low-salary crew (say, flying the Greek flag) trade on a route also served by an identical Liberian-flag ship, manned by an extremely-low-salary crew. Suppose that the RFR's are USD20/ton for the German ship, USD15/ton for the Greek ship, and USD12/ton for the Liberian ship. Clearly, the Liberian ship is the most competitive of the three (in terms of cost), followed by the Greek ship and then by the German ship.

Suppose now that calculations show that, capital costs included, an ATOMOS-type ship manned by flag nationals would save USD5 million over the German ship's lifetime net present costs, and USD3 million over the Greek ship's lifetime net present costs (because German average salaries are higher than Greek average salaries). This would bring the RFR of the German ship down by USD6/ton to USD14/ton, and the RFR of the Greek ship down by USD4/ton to USD11/ton.

The net result is that even though the ATOMOS technology is more profitable on the German ship in terms of lifetime savings and overall RFR reduction, the German ATOMOS-type ship's RFR is still above the Liberian ship's RFR, whereas it is the Greek ATOMOS-type ship's RFR that manages to get below the Liberian ship's RFR. This is so because the Greek ship, being closer to the Liberian one to start with, has the maximum chance to close the gap if its competitiveness is further increased.

In that sense, and to the extent there is a question as to which EU ship should rather get the new technology, it is more likely that this should be the ship that is the most competitive to start with, than the one in which the biggest competitive improvement is realized.

As an aside, one needs no analysis to realize what would happen in the above example if ATOMOS technology is applied to the Liberian ship as well. Assuming its crew is qualified enough to master the advanced technology (an assumption one should not easily dismiss), such a ship would be virtually unbeatable on cost terms (it could have an RFR of USD10/ton, for instance). It could be beaten only if the EU ATOMOS ships offer superior service and reliability, or if these ships are also manned (perhaps with the exception of some high ranked officers) with cheap crews. More about both scenarios later.

4.4 Level III analysis

The approach of the Level III analysis resembles that of Level II, attempting to extend that analysis. A major difference with Level II is that the sample size is now much larger (examine ships from the entire LRS database) so as to attempt to draw some more general conclusions. Another difference with Level II is that since no cost (manning, or other) is included in the LRS database, many variables in Level III have to be estimated, or otherwise assumed, instead of being simply provided from the data collection effort.

Level III makes no attempt to estimate any costs that do not relate to manning. In fact, manning is the only category of cost that is estimated. Then comparison are made among each of the parent ships selected, an ATOMOS-type ship, and a cheap-crew ship, all appropriately defined.

Level III analysis is based on the following assumptions:

The total number of the ships in the LRS database is 25,058. From these ships we select those that fly the following flags:

a) The 12 flags of all EU countries, as defined earlier, that is: Belgium, Denmark (including DIS), France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and United Kingdom.

b) The flags of Finland, Norway (including NIS) , Sweden, Japan, and the US.

The total number of the flags and/or registers is 19 (DIS and NIS ships are listed separately).

We next discard all ships for which the LRS database has no information about the crew number or BHP, and the ones which have crew size less than 11 people.

The remaining ships after all these screens are 1,487, which is the sample size for the Level III analysis. Table 5 shows how these ships break down into major ship types. We note here that in determining "ship type" the LRS database designation was used. Note however that since LRS usually classifies a ship under several categories (e.g., Passenger/Roro/Ferry), the *first label* in such characterization was used to classify each ship into a major ship category. The exception was for passenger roros, for which any ship that had the word "passenger" within its multiple label was put into the "passenger" class, even if its primary label was "roro."

Table 5: Breakdown of 1,487 ships into flags-registries and major ship types.

Each of these 1,487 ships is called a "parent ship." For each parent ship, two equivalent hypothetical ships are considered:

a) An ATOMOS-10 ship, as defined in Level II (6 officers, 4 ratings). It flies the parent ship flag, and is manned by flag nationals.

b) A cheap-crew conventional ship. In contrast to Level II, here a cheap-crew ship *flies the flag of the parent ship.* It differs from the parent in that only the captain and the first officer are flag nationals, the rest of the crew being non-EU nationals paid a very low salary. The reason for examining this alternative (which may be unrealistic or even illegal in some countries under current national legislation) is to assess a policy alternative to an ATOMOS-type ship. Such an alternative is under discussion in several countries (e.g., Germany) as a means to control manning costs, and so we thought it would make sense to see how it would compare with an ATOMOS alternative. Since this is research at the *prelegislative* level, such an investigation is certainly legitimate, at least on a "what if" basis.

Thus, the purpose of this exercise is to estimate and compare annual manning costs for each parent ship of the sample, as well as for its equivalent ATOMOS-type ship, and for the cheap-crew alternative.

Of course, a problem with this scheme is that the LRS database has only technical information, and does not even have crew composition information (as much as it has crew size information). Thus, in making the above comparison, we have to make some (hopefully realistic) assumptions about crew composition and manning costs, not only for the hypothetical ships, but for the parent ships as well.

Manning costs for each of the crew ranks and nationalities assumed are based on collected information on collective labor agreements in various countries, multiplied by a user-defined "surplus factor" (whose default value is assumed to be 1.3). Psaraftis et al (1994a) provides details on how such data was obtained.

The above mentioned data was arranged into 9 databases:

one for the German flag
one for the Danish, Norwegian, Swedish, and Finnish flags
one for the Dutch, French, Belgian, and Luxembourg flags
one for the British and Irish flags
one for the American flag
one for the Japanese flag
one for the Portuguese and Spanish flags
one for the Italian flag, and
one for the Greek flag.

There is also a separate wage database for the cheap-crew ship, which is called the "Russian database" because it contains salary levels for officers and ratings that are of Russian nationality. The reason this nationality was selected is that it constituted the cheapest wage levels found from all data that was collected. We recall that each cheap crew ship has only the captain and the first officer of the same nationality as the parent ship's flag, and all other crew of non-EU low wage nationality.

All these wage databases are connected with the LRS ship database.

The other difficulty in the Level III analysis is the determination of the parent ships' crew compositions. No such information is directly contained in the LRS database, although the crew size is provided (al least for the 1,487 ships). In order to come up with a realistic crew composition for each ship, the following procedure is used:

1) From LRS database, get crew size for the ship. Call this number n.

2) Look at the Official Manning Regulations of the flag of the ship. The determination of the minimum allowable crew size depends on the ship's GRT and, in many flags, on the ship's engine BHP. In addition, some flags divide the ships into "automated" and "non automated" ones. Call this number m.

3) Determine minimum crew composition provided by Official Manning Regulation.

4) If $m = n$, use this as the assumed crew composition of parent ship.

5) If $m < n$ (as is likely), fill surplus (n-m) positions among ship ranks, using a special "surplus crew distribution" algorithm.

The above procedure is more complex than it looks, and proved even more complex to implement in practice, as the Official Manning Regulations at our disposal were reasonably complete only for Belgium, Germany, Greece, the Netherlands, and Italy. Also, it was not immediately obvious what a reasonable distribution scheme for surplus crew should be. Last, but not least, passengers and ferries present the additional difficulty of having sometimes very large crews listed in the LRS database (sometimes on the order of 100 or more), most of which have hotel tasks, the automation of which is beyond the scope of ATOMOS. Clearly, it would not make sense to compare a 100-crew passenger ship with an ATOMOS-10 ship.

The approach that was followed is based on the following broad principles:

a) Hotel crew is not part of the manning cost equation for passengers and ferries.

b) Surplus crew distribution spreads surplus crew in a balanced way among several ranks. Over a certain level, crew is designated to the "able body" rank.

c) All manning calculations are done for a single set of crew team. This has some implications for those ships that have multiple crews (see later).

d) For flags for which we did not have Official Manning Regulations, the minimum crew assumed was that of some other country, using a grouping similar to the one used for wages.

With these assumptions, we now proceed to the presentation of results.

The first question in the Level III analysis is for what percentage of these ships the NPV of the time stream of manning cost differentials between the parent ship and the equivalent ATOMOS-10 ship, taken over 25 years, exceeds the additional capital cost of the ATOMOS technologies. If the answer is yes, then the ATOMOS ship is more competitive than the parent ship.

The answer to this question depends on two factors:

(a) the additional capital cost of the ATOMOS technologies, and

(b) the real cost of capital i (or discount rate).

We examined capital costs ranging from USD1 million to USD5 million, and i ranging from 0% to 10%, and the results are as follows:

1) If the rate is 0% (something that favors ATOMOS ships, as noted earlier, but is probably unrealistic), virtually all ATOMOS ships are more competitive than their equivalent parent ships. Even if the cost of the new technologies is USD5 million, 88% of the ATOMOS ships are more competitive.

2) If the rate is 10% (the worst possible case for ATOMOS ships), 96% of them are still more competitive for a cost of new technologies equal to USD1 million, 88% if the cost is USD2 million, and 49% if the cost is USD5 million.

Given that the 5 million figure is probably on the high side, these results paint a very favorable color for ATOMOS-type ships, even for high interest rates. This is true for all flags for all ship types examined.

Table 6 provides the complete picture for the USD2 million, 10% case for every type/flag combination.

Table 6: Ships for which NPV of lifetime manning cost differentials is at least USD2 million (i=10%).

Taken by flag, the percentages of ships in which an ATOMOS ship is more competitive than its parent ship are as follows:

Belgium: 100% (1 ship out of 1).
Denmark: 100%.
DIS: 79%.
Finland: 93%
France: 86%.
Germany: 87%.
Greece: 94%.
Ireland: 43%.
Italy: 83%.
Japan: 94%.
Luxembourg: 82%.
Netherlands: 42%.
NIS: 98%
Norway: 87%
Portugal: 80%.
Spain: 81%.
Sweden: 85%
UK: 82%.
USA: 100%.

Taken by major ship type, the percentages are:

Bulk carriers: 94%.
Containerships: 93%.
General cargo ships: 43%.
LNG carriers: 82%.
OBO carriers: 100%.
Passenger ships: 99%.
Roros: 87%.Tankers: 86%.
Ferries: 100%.
Other types: 83%.

These results, coupled with those of Level II, tend to support the following general conclusion:

Conclusion No. 1: Over a broad sample of ships, ship types, and flags (all EU flags included), an ATOMOS-type ship manned by a crew of 10 is likely to realize significant lifetime cost savings over its equivalent conventional ship. This means that ATOMOS-type technologies are likely to significantly improve the competitiveness of the EU fleet.

More difficult seems to be a differentiation of the above results by flag. In particular, it is not absolutely clear from these runs whether or not ATOMOS technologies favor expensive flags over cheaper flags (Denmark's percentage is 100%, whereas Greece's is 94%, and the Netherlands' is only 42%). So we feel that these results cannot support a general conclusion linking salary levels in a flag with possible improvement in fleet competitiveness because of ATOMOS technologies.

As far as ship types are concerned, passenger ships, OBO carriers, and ferries are ranked first, bulk carriers and containerships follow closely, and general cargo ships are ranked last.

Some interesting remarks can be made if one examines specific flag/ship type combinations. Note for instance that although ATOMOS technologies favor 10 out of the 15 containerships that fly the Dutch flag in this database, they favor none of the 17 Dutch general cargo ships in the database. This is probably due to the fact that ATOMOS technologies are more likely to favor larger parent ships (e.g, containerships) than smaller (e.g, general cargo).

Note also that the savings in certain categories of ships that have multiple crews (such as passenger ships and ferries) will be even higher, for all these calculations were carried out *per single set of crew team* . If a ship has 5 rotating crews, its savings will be 5 times the computed value.

The other major question in Level III is the result of the comparison between an ATOMOS-10 ship and its equivalent cheap-crew ship (as defined earlier). This is presented in Table 7. The table presents how many ships from each type/flag combination achieve a lower manning cost for the ATOMOS-10 ship than for the cheap-crew ship. We call such ships "ATOMOS-favorable."

An important clarification is in order: Since the definition of an ATOMOS-favorable ship includes only manning costs but does not include capital costs, *the possibility that a ship is ATOMOS-favorable does not necessarily mean that the corresponding ATOMOS-10 ship will be more competitive than the equivalent cheap-crew ship.* The reverse however is true, because if a ship is not ATOMOS-favorable there is no way that the ATOMOS-10 ship can be more competitive than the equivalent cheap-crew ship.

Therefore, "ATOMOS-favorability" is a only a necessary, but generally not a sufficient condition for ATOMOS-competitiveness. This means that this concept can be used mainly to identify cases where an

ATOMOS-10 ship is definitely less competitive than the equivalent cheap-crew ship, and that the comparison in terms of competitiveness is liberal in the sense that the percentages of ATOMOS-favorable ships are always upper bounds on the percentages of ATOMOS-competitive ships.

Table 7: ATOMOS-favorable ships.

Several remarks can be made from this table:

1) The overall percentage of ATOMOS-favorable ships is 28% for the 19 flags/registers examined, 36% for the 15 European countries (including EFTA), and 51% for the 12 EU countries combined.

2) The percentages of ATOMOS-favorable ships by flag/register are as follows:

Denmark, DIS, Finland, Japan, Norway, NIS, Sweden, and USA: 0%, or very close to 0%.
Belgium: 100% (1 ship out of 1).
France: 60%.
Germany: 17%.
Greece: 89%.
Ireland: 43%.
Italy: 62%.
Luxembourg: 71%.
Netherlands: 21%.
Portugal: 25%.
Spain: 30%.
UK: 81%.

Noting again that these percentages are *upper bounds* on the percentages of cases for which an ATOMOS-10 ship is more competitive than an equivalent cheap-crew ship, these results tend to support what was stated as a conjecture in Level II (Conjecture No. 2). We believe that a more general conclusion can now be supported:

Conclusion No. 2: For those ships (EU flags included) that are manned by expensive crews an ATOMOS-type ship manned by a crew of 10 is likely to be less competitive than an equivalent conventional ship that flies the same flag, has flag nationals only for the captain and first officer position, and non-EU low salary personnel for the rest of the crew.

This is probably why the Scandinavian countries and, to a lesser extent, Germany and the Netherlands (not to mention Japan and the US) have the lowest percentage of ATOMOS-favorable ships, and why Greece has the highest. We feel that no concrete conclusions for the other flags can be reached.

3) The percentages of ATOMOS-favorable ships by ship major type are:

Bulk carriers: 38%.
Containerships: 19%.
General cargo ships: 16%.
LNG carriers: 13%.
OBO carriers: 41%.
Passenger ships: 53%.
Roros: 16%.
Tankers: 24%.
Ferries: 64%.
Other types: 18%.

We feel that no general conclusion from these figures can be drawn. Passengers and ferries are favored again here, but it is precisely for these types of ships (which still operate in cabotage-restricted trades in some countries) that the cheap-crew alternative described in Level III is the least likely to be implemented.

5. Conclusions

Before we further discuss the results of this work, we first make a list of issues that are, in our opinion, still inconclusive and merit further research:

1) The possible indirect costs and benefits of ATOMOS-type technologies are not yet thoroughly documented.

2) The economic impact of such technologies on the safety and reliability of an ATOMOS-type ship is an area that needs further research. In particular, the possible impact of lower manning in the management of emergency situations needs further investigation.

3) No concrete conclusions could be reached in our analysis on whether for some specific flags and ship types an ATOMOS-type ship is more competitive than a cheap-crew ship, as defined in Level III.

4) No concrete and general conclusions can be reached on the cost-effectiveness of specific, individual ATOMOS technologies.

In spite of these areas of non-conclusion, we believe that the overall analysis of this document supports the general premise that ATOMOS-type technologies would add to the competitiveness of many merchant fleets, the EU included. The "cheap-crew" alternative in Level III was presented more as an intellectual exercise to see how really competitive is an ATOMOS ship, and less as a proposal for policy implementation. Nevertheless, it is known that ideas similar to this alternative are under discussion in some countries, and so we believe that our analysis can shed more light into these discussions.

Our analysis has centered on costs and benefits that could be quantified with some confidence, with a focus on those that are directly impacted by crew reduction and the introduction of new technologies. As such, cost criteria such as RFR received a prominent focus. However, competition in shipping is not always based on cost alone. Service competition is sometimes important too, particularly in the liner and passenger/ ferry markets (as much as it is not that important in the charter market which is price competitive).

Port turnaround time and speed are two service criteria that can be impacted by ATOMOS-type technologies, albeit indirectly. The question is to what extent ATOMOS technologies improve also the service competitiveness of the ships to which they are applied. After all, a ship that offers truly superior service might be more competitive than the competition, even if it is more expensive to operate.

Although the answer to the above question is "probably they do, possibly substantially," as all service-related costs and benefits fall under the indirect consequence category, comprehensive data that can be used to support a definite conclusion is not really available, and further research into this issue is warranted.

Which shipowners might invest in ATOMOS technologies? The ATOMOS project attempted to answer this question mainly for EU shipowners. We do so here as well, but we also attempt to make some more general points for other flags, to the extent possible.

We first note that the answer to the above question is unclear at best, for it depends on many unpredictable factors (such as the marketing strategies of vendors of ATOMOS equipment, to state just one). However, we believe that the analysis reported here sheds some light on this issue. We need not add to the Level III results as they are differentiated by major ship type. However, the differentiation by flag reveals some important issues.

On the one hand, it is perhaps obvious to expect that the greatest economic benefits from an ATOMOS-type ship should be realized on a "high-salary" ship (in terms or higher lifetime crew cost savings). This means that shipowners in "expensive" flags (such as Germany, Scandinavian countries, Japan and the United States) would have the greatest (among other shipowners) economic incentive to invest in such technologies. The NPV of the savings they would realize over the lifetime of the ship would be the highest, among other shipowners.

On the other hand, our analysis has strongly indicated that it is mainly in lower-salary EU flags that ATOMOS-type ships have the greatest chance of beating the competition, that being conventional low-salary non-EU ships. This is in spite of the fact that from the viewpoint of a lower-salary European Union shipowner, the economic incentive for investing in an ATOMOS-type ship is not that impressive (at least as compared to the equivalent incentive of a shipowner in a high-salary EU flag). Since the lower-salary EU flags are the ones that are the closest to the foreign competition (in terms of cost), this brings them in a better position to close the "competitiveness gap" by crew reduction, given the gap is smaller for them than it is for higher-salary EU flags.

For the European Union, this raises the question what, if any, should be an appropriate policy on this issue, assuming a willingness to exploit ATOMOS-type advances so as to increase the EU fleet competitiveness. Assuming that a shipowner can readily identify the economic benefits of an ATOMOS-type ship (something that is perhaps less obvious than it looks to the developers of such technologies), the most likely result will be that ATOMOS technologies will be implemented more on higher-salary EU flags and less on lower-salary EU flags. That may result in the largest overall NPV savings for the EU fleet, but will not necessarily improve the EU fleet competitiveness vis-a-vis foreign competition, as the latter would still be cheaper to operate.

A question then is what might be an appropriate incentive structure in order for ATOMOS technologies to be adopted by EU shipowners who operate lower-salary ships (such as Greeks, for instance). As much as this would have the greatest chance of beating conventional cheap-crew non-EU ships, this would also be the least likely scenario to occur if a "laissez faire" policy is followed, since such EU shipowners would have the least incentive in making this happen.

Parallel considerations apply also for other flags. Inasmuch as little or no data has been collected and little or no similar in-depth analysis has been made for other countries (e.g., for the Americas and countries in the Pacific), it is plausible to conjecture that it is mainly in lower-salary flags of the Western hemisphere that ATOMOS-type ships have the greatest chance of winning the competitiveness game. This is in spite of the fact that from the viewpoint of a lower-salary shipowner (e.g, a South American shipowner) the individual incentive for investing in an ATOMOS-type ship is not that impressive (at least as compared to the equivalent incentive of a shipowner in a high-salary flag such as the US or Japan, which is the highest).

An important caveat: Education and training of personnel for ATOMOS-type ships is an issue of paramount significance. This needs to be addressed not only at the national level, but also at the international level. The assumption in all of our analyses has been that ATOMOS-type crews have received appropriate training and certification. This means that it might be impossible to implement such ships in countries that cannot supply crews adequately trained for this purpose. Another important ramification of this assumption is that a highly skilled crew will generally be more expensive in terms of salary than a conventional crew, implying that an ATOMOS-type ship that is also a low-salary ship may be unlikely to occur.

The hypothetical cheap-crew EU ship alternative presented in the Level III analysis (only captain and first officer are flag nationals, the rest are low-salary non-EU nationals) is obviously an extreme case. If we wish to generalize, it is clear that such an alternative is simply illegal in some countries, which require most or all of the crew to be flag nationals (the United States being an example). The other extreme case is certainly an ATOMOS-type ship manned only by flag nationals. We believe that the analysis presented here supports the recommendation to investigate intermediate cases.

This may call for the relaxation of the flag nationality requirements that exist in several countries, if the fleets of these countries are to seriously compete against the world fleet. The establishment of parallel international registers (as done in several European countries, e.g, DIS, NIS) might be a way to implement such a relaxation.

Acknowledgments

Project ATOMOS was funded by the Commission of the European Communities, Directorate General for Transport, Contract Number 8101-CT91-2301. Over the period 1992-1994, the NTUA team included research assistants V. Adalis, C. Andronikidis, L. Babilis, P. Bartzis, V. Boulmetis, Y. Chiotopoulos, C. Dilzas, D. Skaleos, T. Stamatellos, and P. Vranas. We are indebted to a long list of individuals (too long to be included here) for providing data, reports, and other useful information, and for commenting on the results of this work.

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