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Cost-Benefit Analysis for Ship Automation Retrofit: The Case of Icebreaker *Frej*

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A detailed cost-benefit analysis of a retrofit of the Advanced Technology to Optimise Maritime Operational Safety (ATOMOS) platform on board icebreaker *Frej* is presented. After accurately determining the relationship between the costs and benefits, an analysis is implemented in order to assess the most basic advantages and disadvantages of the suggested retrofitting action in monetary terms. A two-step approach is adopted. The first step is to define the major categories of the ship operational aggregate costs and benefits (for example, the actual cost of the ATOMOS platform and of equipment not part of the ATOMOS platform but still necessary for its installation and operation, or the expected crew decrease because of the higher degree of automation). The second step is to examine the various basic components of these categories (for example, administration and training cost, required automatic radar plotting aid [ARPA] and electronic chart display and information system [ECDIS] equipment acquisition cost, fuel benefits, and insurance benefits). The cost-benefit analysis performed is followed by a sensitivity analysis of the most important factors affecting the net present value of the investment. It is shown that it takes about 5 years for the ATOMOS retrofit to be fully paid back by the annual savings it offers and it takes about 6.5 years for the net present value of the investment to turn positive. This coupled by the increased vessel safety justifies the decision to retrofit *Frej* with the ATOMOS platform. Furthermore, it is found that the cost of the ATOMOS platform, the benefits from crew decrease, and the interest rate are those factors that essentially determine the profitability of the investment. In the case of *Frej*, it is concluded that the retrofit is worth undertaking for the majority of future scenarios.

Introduction

THE PURPOSE of this paper is to present a cost-benefit analysis (CBA) for the retrofit of innovative ship automation systems, as implemented on board the Swedish icebreaker *Frej* in the context of the project Advanced Technology to Optimise Maritime Operational Safety: Intelligent Vessel (ATOMOS IV).[2] ATOMOS IV was the last among a series of previous EU-funded projects (ATOMOS, ATOMOS II, DISC, and DISC II), whose main thrust was to develop and demonstrate advanced automation technologies in order to enhance the competitiveness and safety of the European fleet.

The central premise behind this work has been the realization that automation technologies that reduce manning can, under certain circumstances, accrue benefits to the ship owner, not only in terms of a reduced payroll, but also in terms of increased safety as well as other attributes. Even though such a premise is conjectured to be valid for any type of ship, the extent to which this is true or not would depend on the particular circumstances and would be case specific.

In terms of CBA, two main modes seem relevant: the first one concerns new buildings and the second one, already operating vessels. In the first case, a comparison should be made between an automated newly built ship and an "equivalent" conventional (still) newly built one. Here, "equivalence" means that both vessels have the same payload, speed, and other operational parameters. The relevant question would then be which, among these two vessels, is superior in terms of specific predefined cost-benefit criteria? Or, given the shipowner has a choice, which of the two vessels should he prefer? In the second case, which is actually the subject of this paper, a ship owner who considers the conversion of an existing conventional vessel to an automated one should ask instead: Given the vessel, is it worth retrofitting it with advanced technologies from the point of view of cost and benefits?

In general, the prime motivation for any ship owner undertaking a retrofit from a conventional to an automated configuration is the economic savings realized from the reduced manning that such a configuration could entail. Reduced manning produces considerable savings in operating costs and thus increases the competitiveness of the vessel. As many worldwide flags have traditionally suffered a loss of competitiveness, retrofits that reduce manning costs are of considerable importance. Even for a noncommercial vessel, reducing such costs can be valuable, because this frees financial resources for other purposes. At the same time, it should be realized that manning costs are certainly not the only variable affected by a vessel retrofit. All important ramifications of the retrofit should be taken into account when performing a CBA.

In the context of the ATOMOS IV project, such a retrofit took place. It concerned the real-life implementation of the technologies developed under this project (from now on referred to as ATOMOS technologies or ATOMOS system) on board *Frej*, an icebreaker owned by the Swedish Maritime Administration. *Frej* (see Fig. 1) is one of a series of six icebreakers employed by the same administration and operating in the Swedish territorial waters during the entire icebreaking period (usually from December to April).

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[2] ATOMOS IV, EU DG-TREN Contract No. 1999-CM.10540. Twelve partners from eight countries participated in this project, which lasted from 1999 to 2003.

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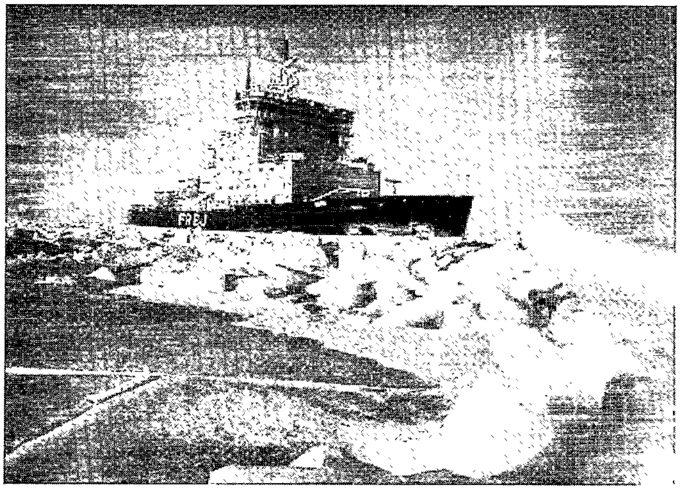

Fig 1 The *Frej* during the ATOMOS trials

Even though the detailed description of the technologies implemented under this project is beyond the scope of this paper (Ventikos et al 2002a, 2002b, 2002c, 2003, Raffetti et al 2002, Dilzas et al 2003), we provide a very brief overview of what an ATOMOS system is. This also helps one to understand the various equipment/systems that are considered in the CBA.

The ATOMOS system as a package is a complete navigational bridge, including consoles, operator workstations, panels, levers, joysticks, and so forth. The heart of ATOMOS is the integrated ship control (ISC) system with a data network that connects together all vessel systems, including traditional alarm, control, and navigation systems. The ATOMOS concept is considered "open." This means that any system or equipment can be connected to the data network and thereby exchange data with any other application.

The ATOMOS system, as it has been installed on *Frej*, and can also be installed on any commercial vessel with minor or no modifications, consists of the following subsystems or main components:

- Shipwide control data network
- Automation: integrated ship control (ISC) system, including operating consoles
- Navigation: radar/ARPA and ECDIS consoles
- Communication: digital radio link (Inmarsat B High Speed), automatic identification system (AIS) transponder
- Administration: computer-based training system, planned maintenance system, electronic technical manuals, and maritime black box
- Arrangement: ship control center (SCC) layout and consoles.

The ISC architecture is outlined in Fig. 2 and is based on a three-layer configuration of different information technology (IT) and automation components: workstations, process controllers, servers, and so forth.

The top layer is a non–real-time administrative network typically realized with office automation network technology. It interconnects non–safety-relevant administrative applications, such as maintenance planning or purchasing management. Furthermore, it provides access to the real-time world through a gateway that protects the real-time network by prioritizing access from the administrative applications.

The central layer is a real-time ATOMOS network for all safety and ship operation–related applications, such as navigation or engine control.

The bottom layer is the device level with different local input/output (I/O) busses, field busses, serial interfaces, and dedicated lines, such as 4–20 mA signals. All relevant vessel systems are interfaced at this level. Such systems and/or equipment include among others navigation instruments, machinery control systems, steering gear, fire detection system, control systems for auxiliary equipment, and electrical power generation.

The architecture is based on a client-server structure, where the server "provides" data and the client "uses" data. Servers are therefore typically present on the floor level, whereas operator workstations are clients. A node can act as

Nomenclature

AMC = alarm, monitoring, and control
AIS = automatic identification system
ARPA = automatic radar plotting aid
ATOMOS IV = Advanced Technology to Optimise Maritime Operational Safety: Intelligent Vessel
CBA = cost-benefit analysis
CBT = computer-based training
DGPS = differential global positioning system
DG-TREN = Directorate General-Transport and Energy (Commission of the European Communities)
DISC II = Demonstration of Integrated Ship Control by way of Inter-European Implementation
ECDIS = electronic chart display and information system
EU = European Union
GPS = global positioning system
HF = high frequency
IMO = International Maritime Organization
I/O = input/output
IRR = internal rate of return
ISC = integrated ship control
ISDN = Integrated Services Digital Network
ISL = Institute of Shipping Economics and Logistics
IT = information technology
ME = main engine
MS = Microsoft Corporation
NPV = net present value
NRC = National Research Council
OS = operating system
P&I = protection and indemnity
PBP = payback period
PLC = programmable logic controller
RFL = remaining fiscal life
RMC = reefer machinery cycle
SCC = ship control center
UPS = uninterruptible power supply
VHF = very high frequency

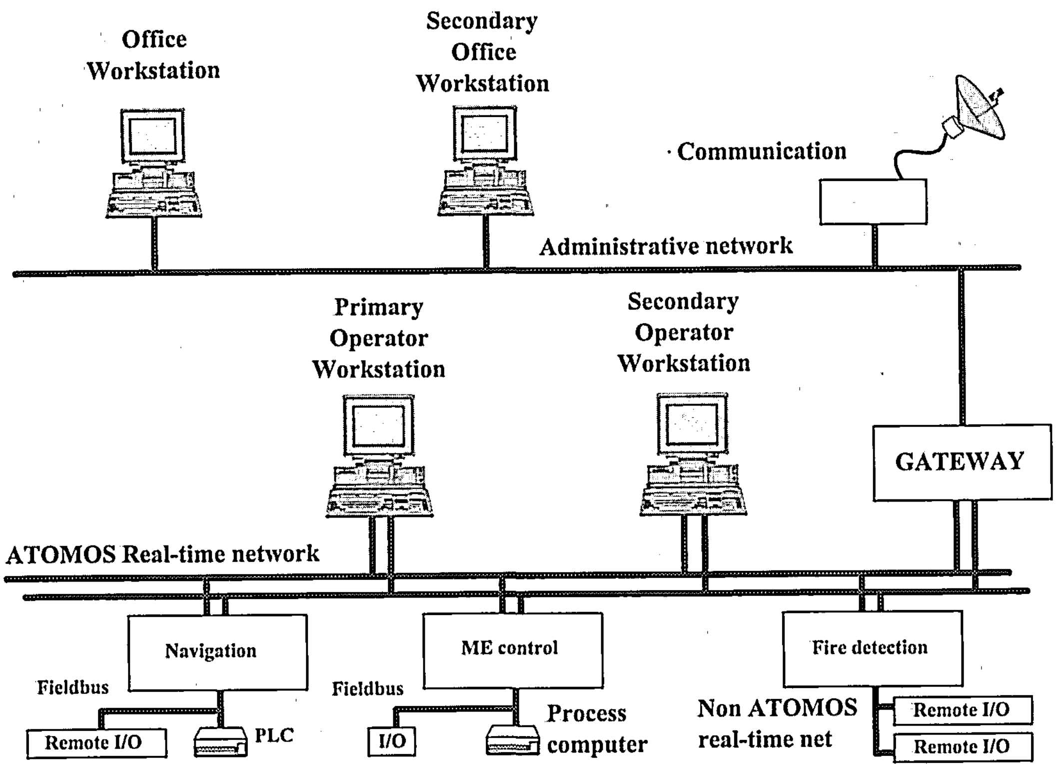

Fig 2 Physical architecture of the ATOMOS ISC system

client and server at the same time depending on application demands. The role of an application is defined by the main direction of data flow, and it is possible that one application takes both roles.

The client-server architecture is specifically adapted to the real-time process control network but can also be extended to the administrative network depending on the communication functionality of the administrative net and the gateway. Special attention is paid when control applications interact with the non–real-time world because of the lack of deterministic timing behavior.

In the absence of any alternative architecture, it is our basic assumption that this basic architecture would be present in any ship type (not just in the *Frej*) that would be retrofitted with the ATOMOS platform. In the event that departures from such architecture occur, the relevant modifications should be noted. Such modifications are not expected to affect the methodology of this report, although they will likely affect the outcome of the calculations.

Before we proceed, we should cite several related references. Holder and Moreby (1986), NRC (1990), Pollard et al (1990), ISL (1993), and Grossmann (1993) study the general subject of ship manning. To our knowledge, the specific subject of CBA of advanced shipboard technologies that reduce crew has not received extensive attention. Marcus and Weber (1994) examine issues of competitive manning in US merchant vessels, whereas Psaraftis (1995, 1996) assesses the impact of automation technologies on the overall competitiveness of the EU fleet. In a separate component of the research carried out within the same project, Lyridis et al (2005) address the issue of crew composition as a function of ship automation level.

The rest of this paper is organized as follows: The next section gives the general framework of the CBA for icebreaker *Frej*; the "Cost elements" section collects the expected costs of the ATOMOS retrofit on *Frej* and the "Benefit elements" section the respective benefits; the "Implementation of methodology" section describes the method implementation, the results of the analysis, and makes a sensitivity analysis of various important factors; and the "Conclusions" section discusses the results of the study.

General framework

The retrofit of *Frej* consisted of equipping the vessel with all the necessary hardware and software that would enable it to function with an ATOMOS bridge and an integrated control system. Thus, *Frej* was essentially transformed from a "conventional" to an ATOMOS vessel. Extensive tests and sea trials were conducted and led to the final demonstration of the technologies implemented, when the overall control of the vessel successfully switched from the conventional operating mode to the ATOMOS mode and back to the conventional mode.

It is assumed that *Frej* both in the conventional and the ATOMOS mode performs the exact same operations. Such an assumption is not necessarily true for a commercial vessel, but it was thought that the nature of the icebreaker's assignment permits this postulation.

The costs of the ATOMOS retrofit for the conventional icebreaker, or for any vessel, can be divided into the following four categories:

- ATOMOS platform cost
- Non-ATOMOS equipment cost
- Cabling cost
- Extra cost.

The ATOMOS platform cost includes the cost of purchasing and installing the basic components of the ATOMOS platform (including software), along with the annual cost of maintaining, upgrading, servicing, and operating these components and training the crew (Stopford 1997). The crew training cost for the ATOMOS platform installation and operation is not calculated on a yearly but on a 5-year basis.

The identification of the non-ATOMOS equipment aims to establish an "average" shift cost in technology and level of automation and to ensure compatibility of the non-ATOMOS equipment with the ATOMOS platform standard. An example of non-ATOMOS equipment cost is the cost of upgrading a manual valve to automatic.

The cabling cost component is an essential part of the complete ATOMOS retrofit as it represents the cost of all the cables used during retrofit that connect the various ATOMOS and non-ATOMOS systems to the ATOMOS platform. It is important to point out that in the case of the *Frej*, cabling cost was not taken into account, because the basic cables needed for the connection of the systems to the ATOMOS platform were already available on *Frej*. In general, the cost of cabling can be a substantial part of the retrofit cost.

The extra cost component refers to any other cost a ship owner would have to pay in order to retrofit his vessel. In particular, it includes the lay-up cost and the additional cost for sailing to the shipyard. Moreover, during retrofit, the ship must stay off-hire, thereby losing a potentially substantial amount of income. Any loss of income or, more precisely, of profit during the retrofit operation is an opportunity cost and should be taken into account. Talking about various ship types, this opportunity cost should be calculated for the duration of the retrofit, adding the travel time to the shipyard. It is very crucial to emphasize the necessity to include this opportunity cost, because ship owners schedule maintenance and repair according to the market situation. This opportunity cost is also related to the vessel type, age, and dimensions. Yet, it must be noted that it is really the difference in time and lost opportunity cost for only that incremental portion of the vessel's time out of service that is associated with the ATOMOS retrofit that can be legitimately considered as an ATOMOS cost. Similarly, if the vessel needs to travel for the ATOMOS retrofit to a shipyard that has higher costs or is further away than the shipyard that can be used for the remaining scheduled maintenance, it is this additional cost and time that will be considered in the CBA.

In this case, however, *Frej* is not a commercial vessel and it is supposed to operate only during the ice-breaking season, while the ship was actually at the shipyard for the retrofit outside the operational season. It is thus assumed that the extra cost component for *Frej* is equal to zero.

The benefits that might be obtained from the implementation of the ATOMOS platform are quantified mainly in terms of a possible reduction of the running costs. These are grouped into the following components (Stopford 1997):

- Crew
- Insurance
- Maintenance
- Fuel
- Safety.

Crew benefits arise from the reduction of crew size due to the ATOMOS retrofit, insurance crew benefits are cost savings due to lower insurance fees, maintenance benefits arise from the cost savings due to better and more efficient maintenance procedures, fuel benefits arise from the cost savings due to the lower fuel consumption of the vessel, and the safety benefits arise from safety aspects with respect to environmental efficiency of the vessel and the loss of human lives.

The general formula for the calculations that were used in the cost-benefit methodology for the ATOMOS platform installation on board *Frej* is given by the following equation:

$$\mathrm{NPV} = \sum_{n=0}^{RFL} \frac{B_n - C_n}{(1+i)^n} \tag{1}$$

where:

- NPV is the net present value of the profit from operating the vessel for a number of years
- B_n is the total amount for the annual benefits
- C_n is the total amount of the annual costs for the ATOMOS retrofit
- i is the interest rate
- RFL is the remaining fiscal lifetime of *Frej*.

The detailed analysis of the aforementioned cost and benefit components is presented in the following paragraphs.

Cost components

The cost of the whole ATOMOS retrofit for icebreaker *Frej* can be divided into two major categories, the C_{INI} and the C_{PER}, where

- C_{INI} is the cost for purchasing and installing the ATOMOS platform, including the cost for additional machinery, the cabling costs, and the extra cost as they are described in the beginning of this section ($C_{INI} = C_0$).
- C_{PER} is the periodical costs of the ATOMOS platform, including the maintenance, upgrade, training, operation, and service costs. This cost category will be symbolized with an extra indicator (n) that refers to a specific year of the vessel's lifetime (C_{PERn} are the annual costs of the ATOMOS retrofit for the year n).

The initial cost, C_{INI}, is thus divided in four categories, the C_{ATI}, C_{NAT}, C_{CAB}, and C_{EXT}, where

- C_{ATI} is the total cost of purchasing and installing the ATOMOS platform equipment
- C_{NAT} is the total cost of non-ATOMOS equipment
- C_{CAB} is the total cost for cabling (= 0 as per above)
- C_{EXT} is the extra cost (= 0 as per above).

The periodical cost C_{PERn} can be divided in two categories, the C_{TRAn} and the C_{OTHn}, where

- C_{TRAn} refers to the cost of crew training. This cost has been assumed to be calculated not on a yearly basis, but every 5 years. Thus, this cost category is equal to zero for years 0, 2, 3, 4, 5, 7, 8, 9, 10, 12, and so forth of the retrofitted vessel's lifetime.
- C_{OTHn} covers all the rest categories of the ATOMOS retrofit annual costs, which are the operating, the maintenance, the upgrading, and the service costs.

Benefit components

The total annual benefits B_n calculated in the NPV consist of six major components: B_{CRn}, B_{MNTn}, B_{INSn}, B_{FUEn}, B_{SAFn}, and B_{ENVn}, where

- B_{CRn} is the value of benefits from crew reduction
- B_{MNTn} is the value of benefits from the reduction of the vessel maintenance costs
- B_{INSn} is the value of benefits from the reduction of insurance that a ship owner is required to pay
- B_{FUEn} is the value of benefits from reduced fuel consumption
- B_{SAFn} is the value of benefits from increased safety (fewer losses of life) of an ATOMOS retrofitted ship
- B_{ENVn} is the value of benefits due to better environmental efficiency of the vessel.

Then the general formula for the NPV calculation (1) can be presented in the form of the following equation:

$$\text{NPV} = \sum_{n=1}^{RFL} \frac{B_{CRn} + B_{MNTn} + B_{INSn} + B_{FUEn} + B_{SAFn} + B_{ENVn} - C_{TRAn} - C_{OTHn}}{(1+i)^n} - (C_{ATI} + C_{NAT} + C_{CAB} + C_{EXT}) \quad (2)$$

where i is the interest rate and remaining variables have been defined above.

We now proceed with the detailed evaluation of each of the above categories of costs and benefits.

Cost elements

ATOMOS platform cost

The ATOMOS platform on *Frej* is specifically focused on automation and navigation procedures. For the purposes of our methodology, it has been divided into the following two basic categories:

- ATOMOS equipment for navigation equipment and bridge systems
- ATOMOS equipment for alarm monitoring and control systems.

Tables 1 through 4 show the basic components for the above categories of equipment and the corresponding cost data for their purchase, installation, maintenance, upgrading, and service, along with the relative indicative cost of crew training required for the operation of these systems (Ventikos et al 2002a, 2002b, 2002c, 2003, Raffetti et al 2002, Dilzas et al 2003). The collection of relevant data has been the result of various questionnaires posed to the ATOMOS IV partners involved in the retrofit activities. The respective questions were in the form of tables related to specific activities on board and the way they are performed. Thus, SAM Electronics provided data on the cost of the navigation equipment and the bridge systems, and Lyngsoe Marine provided data about the cost of the alarm monitoring and control equipment. The cost of the additional software of the ATOMOS platform was provided by Logimatic, and the Danish Maritime Institute (currently, Force Technology) provided the cost for some additional equipment of the ATOMOS platform.

More specifically, Table 1 shows the cost of navigation and bridge systems and equipment. Table 2 presents the various costs of alarm monitoring and control equipment.

Another cost component is software. Software that is delivered with various pieces of equipment is not examined here because it is considered part of the hardware package (e.g., software to operate the radar). There is, however, software developed specifically within the context of the ATOMOS IV platform. Such is the software developed for the planned maintenance system and the electronic technical manuals (Venturino et al 2002). The corresponding training, operating, and maintenance costs are provided on an annual basis. This cost is given in Table 3.

Finally, there is some additional cost for equipment that is specific to the installation on *Frej* (such as additional chairs or cable extensions). Although these cannot be considered part of the ATOMOS platform, they are required for its operation on *Frej* and should formally be considered part of the ATOMOS equipment. (This cost category is different from the extra cost category defined in the "General framework" section.) The cost for this equipment is given in Table 4.

Summarizing the above data, the total cost of the ATOMOS equipment on *Frej* is given in Table 5.

Thus, the total amount for purchasing and installing the ATOMOS equipment is €996,769 while the annual cost of maintenance, operation, and upgrading this platform rises to €28,477. The cost of crew training is €153,597 for the first year. The training courses for the crew are assumed to be carried out every 5 years, and the cost of each course is half of the above amount, namely €76,799. It should be noted that the way such costs would evolve in future applications of the ATOMOS platform is unclear. Some costs may increase while others may decrease.

Non-ATOMOS equipment cost

An indicative list of potential non-ATOMOS equipment required for any retrofit is shown in Table 6 (Boegh & Noergaard 2001).

It should be noted here that the above list is not specific for the icebreaking vessel *Frej*, but it is formed in such a way that it can be used for the majority of all ship types. Nevertheless, this list is still not exhaustive, as other types of potential non-ATOMOS equipment, such as cargo handling gear, are not included. Such other types of equipment should be added on a case-by-case basis, as appropriate.

The cost of non-ATOMOS equipment on *Frej* was provided mainly by the Swedish Maritime Administration and by the respective equipment manufacturers. Making several assumptions, it was estimated that the total cost for this cost category is approximately €70,000. This can be considered as rather low, but it was estimated to be of the correct order of magnitude because the basic non-ATOMOS components were already installed on *Frej*. If the actual figure is much different, the basic cost calculations should be performed again.

As mentioned earlier in the "General framework" section, cabling and extra costs do not apply to *Frej*.

Benefit elements

The five categories of benefits as they have been described earlier in the "General framework" section are examined in more detail in the following paragraphs.

Crew benefits

The manning cost depends on the Swedish flag rules and regulations about crew composition and wages. The detailed crew composition of the icebreaker before and after the ATOMOS retrofit procedure, as well as the salaries per month for each one of the crew members, are given in Table 7.

It can be derived from Table 7 that the difference between the two manning crew costs is €246,848 per year, taking into account 14 monthly salaries per year, or a reduction of about 30%. It is evident that the savings for the ship owner (Swedish Maritime Authority) from the retrofit of the ATOMOS platform on board the icebreaker are really significant from the point of view of manning cost.

Maintenance benefits

Maintenance is one of the major components of the total cost that a ship owner (in this case the Swedish Maritime Administration) is obliged to cover in order to ensure the safe operation of the vessel. Maintenance policies for a conventional ship differ from marine company to marine company and even from vessel to vessel, depending on such parameters as:

- Overall company market strategy
- Maintenance schedule, policy
- Flag
- Class

Table 1 Cost of navigation equipment and bridge systems (*N*th cost is the cost for the *N*th year)

Navigation Equipment and Bridge Systems	Initial Costs (€)		*N*th Cost (€)	Annual Costs (€)			
	Purchasing	Installation	Training	Operating	Maintenance	Upgrading	Service
Total	345,970	14,300	149,000				24,800
ARPA radar system (X-band)	37,200	2,000	1,000				3,500
12 in. Radar display with ARPA electronics	13,900						
Trackball and radar control panel	1,500						
Radar HR component (X-band)	16,100						
Antenna heating for X-band	400						
25 m X-band waveguide kit	2,900						
Console elements	2,400						
ARPA radar system (S-band) from SAM	42,800	2,000	1,000				4,300
12 in. Radar display with ARPA electronics	13,900						
Trackball, radar control panel, and trackpilot panel	1,800						
Radar HF component (S-band)	23,800						
Antenna heating for S-band	400						
25 m S-band waveguide kit	2,900						
3rd Radar operator place	15,400	1,000	200				1,500
12 in. Radar display with ARPA electronics	13,900						
Trackball, radar control panel	1,500						
4th Radar operator place	15,700	1,000	200				1,500
12 in. Radar display with ARPA electronics	13,900						
Trackball, radar control panel, and trackpilot panel	1,800						
5th Radar operator place	15,700	1,000	200				1,500
12 in. Radar display with ARPA electronics	13,900						
Trackball, radar control panel, and trackpilot panel	1,800						
TFT display at the wing	1,500	100					1,500
TFT monitor	1,500						
MBB and cargo tracking interface	50,000						
Interface included in ARPA radar	50,000						
Track pilot system from SAM	9,000	1,000	1,000				2,000
Trackpilot ATLAS 9401, EI	9,000						
AIS transponder from SAM	12,500	1,000	300				1,200
UAIS DEBEG 3400	12,500						
Inmarsat B HSD satellite system from SAM	28,200	2,000	300				2,800
Inmarsat B satellite terminal with antenna, transceiver, and control unit	27,220						
ISDN router ELSA Tango 1000	1,000						
Inmarsat B HSD satellite system from SAM	28,220	2,000	300				2,800
Inmarsat B satellite terminal with antenna, transceiver, and control unit	27,220						
ISDN router ELSA Tango 1000	1,000						
ECDIS	19,320	1,000	144,300				2,000
21 in. Chartpilot console with trackball, terminal strip, PC electronics (Linux OS)	19,320						
ECDIS CBT			107,300				
Extra CBT			37,000				
NMEA navigation sensors (GYRO, speed log, echo, GPS)	2,300	200	200				200
GPS navigator DEBEG 4422	2,300						
PCs	44,000						
5 PCs for automation monitor control	10,000						
5 PCs for ARPA/ECDIS	10,000						
12 PCs for other auxilliary systems	24,000						
UPS	10,710						
5 units	10,710						
ANTENNAs	9,600						
X-band antenna	9,600						
S-band antenna	9,600						
DGPS	2,200						
DGPS sensor	2,200						
MONITORS	1,600						
4 monitors	1,600						

Table 2 Cost of alarm, monitoring, and control equipment

Alarm, Monitoring, and Control Equipment	Costs, (€)	
	Purchasing	Installation
Total	283,500	168,500
Alarm, monitoring, control	241,500	168,500
Indicators for propeller revolutions, engine power, starting air, water depth, including wind direction and velocity, air and water temperature, ballast water handling	18,000	10,000
Group alarms, fire alarms, bilge alarms, adjustment of watch alarm system, acknowledgment of watch alarm	40,000	40,000
Controls for heeling, keys and control elements for lights and signals	4,000	4,000
Maneuvering recorder	3,000	1,000
Prepare and start-up engines and auxiliary systems control, engine control system	50,000	30,000
Check maneuvering systems control	1,000	1,000
Control and monitor propulsion	65,000	50,000
Execute logging function	2,500	2,500
Shutdown engines and auxiliary systems system	17,000	10,000
Alarm for system failures, fire engine control, collision avoidance, "safe area" limits	6,000	3,000
Heeling system controlled from the SCC	8,000	2,000
Fuel consumption display	2,000	2,000
Status of loading condition stability	5,000	5,000
Monitor electric supply systems	1,000	1,000
Propulsion system control: assess deviations from required system status	5,000	1,000
Steering system control: assess deviations from required system status	5,000	1,000
Automatic restart	2,000	2,000
Back-up power supply	7,000	3,000
Communication	42,000	
VHF × 3	12,000	
PC + headset + tele-exchange	30,000	

Table 3 Cost of software

Software	Costs (€)		Annual Costs (€)				
	Purchasing	Installation	Training	Operating	Maintenance	Upgrade	Service
Total	21,756	154,743	4,597	2,758		919	
Electronic manuals and help systems	10,878	108,778	1,839	919		919	
Software for NT and internet information server; client machine with Win NT and Personal Web Server; manuals; data network connection between client and server; automatic restart; back-up power supply. Includes off-the-shelf applications: Win NT, MS Explorer, MS Data Access Object, etc.							
Planned maintenance system	10,878	45,965	2,758	1,839			
Software for PC and other hardware; Windows NT software, data acquisition and other software; connection to radio link; software for managing and control emergency; automatic restart; SCC emergency backup; back-up power supply							

- Insurance coverage
- International Maritime Organisation (IMO) obligations
- Accidents and breakdowns
- Automation level and equipment
- Vessel route.

After discussions and consultations with various shipping companies as well as the *Frej* owner, it was decided that a percentage of 5% was indicative for the expected reduction in maintenance cost due to the ATOMOS retrofit. Maintenance costs were considered as the cost of the following:

Table 4 Other equipment cost

Other Equipment	Costs (€)
Total	8,000
Wooden console parts and chairs	3,000 + 4,000
Power supply from switchboard	500
Cable for rudder upperback	500
Upgrade of echo sounder	4,000

Table 5 Summarized cost

	Costs (€)		Costs (€/year)				
	Purchasing	Installation	Training	Operating	Maintenance	Upgrading	Service
Navigation equipment	345,970	14,300	149,000				24,800
Alarm monitoring and control	283,500	168,500					
Software	21,756	154,743	4,597	2,758		919	
Other	8,000						
Subtotal	659,226	337,543	153,597	2,758		919	24,800
Total		996,769	153,597				28,477

Table 6 Non-ATOMOS equipment

Category	Equipment Type
Navigation equipment	Direction finder
	Echo sounding device
	Gyro compass
	Radar
	Satellite navigation
	Position fixing device
	Collision radar
	Dynamic positioning device
Communication equipment	Satellite communication
	Radio telephone
	Radio telephone (medium frequency)
	Radio telephone (high frequency)
	Radio telephone (VHF)
Maneuvering equipment	Thrusters
	Stabilizers, number and type
Alarm and control systems	Centralized control station (CCS) indicator
	Machinery control system
Propulsion machinery	Propulsion type
	Number of propulsions
	Type of propulsions
	Prime mover (type of main engine)
	Number of main engines
	Propulsion control system (unmanned machinery space)
Other equipment	Inert gas system (for tankers and bulk carriers)
	Crude oil washing system (for tankers)
	Reefer machinery cycle (RMC) indicator (for reefers)
Loading equipment	Type of cargo gear

- Spares
- Repairs
- Regular maintenance
- Surveys
- Dry docking and special surveys.

According to the ship owner, *Frej*'s maintenance cost reaches €500,000 per year. Therefore, the amount of the accepted reduction for the maintenance of icebreaker *Frej* is approximately €25,000 per year.

Fuel benefits

Specific fuel consumption will not be affected by the implementation of the ATOMOS system, because this specific parameter depends only on the characteristics of the vessel propulsion system. Nevertheless, in a generic approach (other than the specific icebreaking vessel) the annual fuel costs are expected generally to increase, in as much as it has been calculated that an ATOMOS ship will be able to perform more trips for every year of operation than a similar "conventional" one. However, as mentioned earlier, due to the type of the examined vessel, it will be assumed that the vessel both in the ATOMOS and in the conventional mode will perform the exact same operations per year. Therefore, fuel benefits are not considered in the present analysis.

Insurance benefits

Insurance costs that are considered as part of the ship owner's budget are the following:

- A "full cost" policy for the ship (hull and machinery) and damages to third parties in general
- A "P&I" (protection and indemnity) policy essentially for the protection of the vessel crew.

It was decided that the insurance costs and all corresponding possible savings from the retrofit of the ATOMOS platform will be exclusively limited to the part of the P&I Clubs. Moreover, all expected changes from the retrofit of the ISC on board the "conventional" icebreaker are considered to be of the order of €500 per year. Thus, the insurance costs that are taken into account in this model reflect a subjective and small amount of savings.

Safety benefits

As far as safety benefits (including oil pollution and loss of human lives) are concerned, we refer the reader to the extensive study by D'Appolonia (Raffetti 2002). The value provided was equal to about €17,000 per year. It must be noted, however, that this study did not take into account the benefits arising from averted oil pollution, because *Frej* is an icebreaker and the corresponding values should not reflect any significant differences. Furthermore, environmental and safety benefits may accrue to society in general and not necessarily to the ship owner. Therefore, they should not necessarily count in NPV (even for commercial vessels). Of course, even if one does not include these benefits in the NPV calculation, one should probably do so qualitatively, because it should be recognized that although these benefits are difficult to quantify, they would tend to make the NPV more positive than the reported numbers. In that sense, to the extent that an ATOMOS system reduces the likelihood of an accident, there ought to be a way of crediting the system in terms of NPV.

Implementation of methodology

Comparison criteria

All data collected in the "Cost elements" and "Benefit elements" sections were used in the basic NPV equation (2). Table 8 includes all relative results for the subsequent 15 years. It must be noted that the training factor is taken into account once every 5 years during the lifetime of the vessel. It is also crucial to note that the NPV becomes positive between the sixth and seventh year of the remaining lifetime of

Table 7 Crew composition of the *Frej* before and after the ATOMOS retrofit procedure

Crew Rank	Salaries (Swedish Flag) (€/Month)	Number of Crew Members	
		Conventional State	"ATOMOS" State
Captain	4,734	1	1
Chief mate	4,260	1	1
Second deck officer	3,432	5	4
Chief engineer	4,497	1	1
Second engineer	3,550	3	1
Bosun	2,249	1	1
Able body	1,775	3	2
Wiper/oiler	1,775	3	0
Cook	2,367	1	1
Steward	1,775	1	1
Total number of crew members		20	13
Total monthly crew cost		58,342	40,710

Data for *Frej*'s crew composition after the ATOMOS installation are the results derived from a combined approach of the Swedish Maritime Authority and *Frej*'s classification society.

Table 8 Net present value for the ATOMOS retrofitted *Frej* (million €)

	Remaining Vessel Lifetime (years)								
	0	1	5	6	7	10	11	14	15
Benefit	0.000	0.290	0.300	0.310	0.310	0.320	0.320	0.330	0.330
Cost	1.221	0.028	0.028	0.105	0.028	0.028	0.028	0.028	0.105
Balance	−1.220	0.270	0.280	0.200	0.280	0.290	0.290	0.300	0.230
NPV	—	—	−0.190	−0.070	0.080	0.440	0.560	0.840	0.900

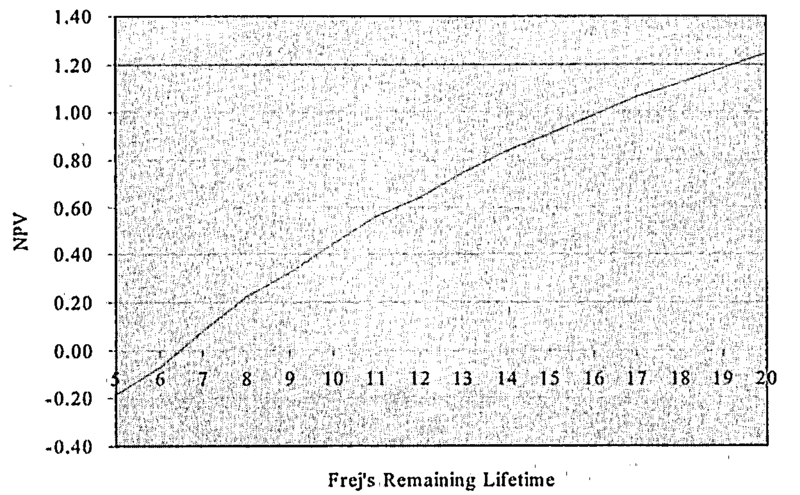

Fig 3 Evolution of the net present value for the ATOMOS retrofitted *Frej*

the vessel. The interest rate was assumed to be 8%. Figure 3 shows schematically the evolution of the NPV calculations.

In addition to the above, two alternative comparison criteria were implemented in order to examine the course of the specific investment (ATOMOS retrofit). These were the internal rate of return (IRR) and the payback period (PBP). Figure 4 gives the IRR of the ATOMOS retrofit to the vessel *Frej* for a period of 10, 15, and 20 years (vessel lifetime).

Table 9 contains the results from the implementation of the PB method for certain years of the remaining lifetime of the automated icebreaker *Frej*. Figure 5 shows the contents of Table 9 in a cash flow chart. According to Table 9, the specific investment seems to be favorable after an even shorter period compared to the NPV criterion. So it takes less than 5 years for the ATOMOS retrofit to be fully paid back by its annual savings.

Sensitivity analysis (NPV criterion)

The CBA, as presented above, is based on specific factors values and cash flows. Due to lack of data or data not well defined with a significant uncertainty range, it was decided to examine how sensitive or robust the project is during a variation of a crucial factor. For the NPV criterion, it was decided that a sensitivity analysis should be conducted for the basic factors of this method. This is done in order to secure the best possible approach for all the upcoming results.

Sensitivity analysis is the most common approach for han-

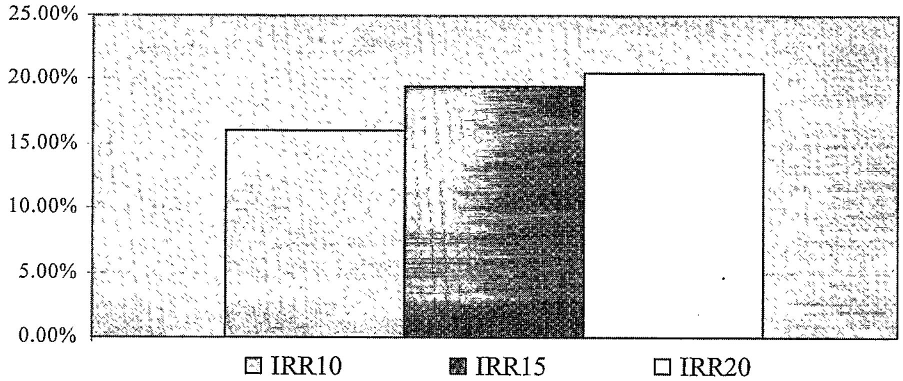

Fig 4 The internal rate of return of the ATOMOS retrofit

Table 9 The payback period approach for the ATOMOS retrofit

Payback Period (million €)		Remaining Vessel Lifetime (years)								
		1	5	6	7	8	9	10	14	15
Initial cost	1.221									
Incomes		0.266	0.276	0.201	0.281	0.284	0.209	0.289	0.300	0.226
Year balance	−1.220	−0.960	0.050	0.260	0.540	0.820	1.030	1.320	2.430	2.650

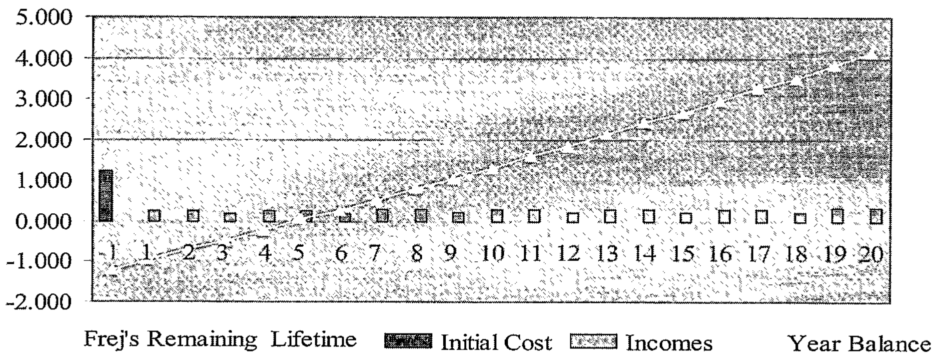

Fig 5 Cash flows and payback period criterion

dling, in practice, the uncertainty of an investment scheme. Because all the selected variables do not influence the calculated result in the same manner, it is crucial that all-important variables should be identified and put in a certain range of values. The acknowledgment of various critical factors-variables is succeeded with the iterative execution of various calculations, alternating each time the value of one variable (and considering the rest of them as constants). Due to lack of existing relative data, the corresponding range of values was formulated in a representative manner in order to be able to comprehend all possible situations and conditions for a time period of 15 years. The following uncertainty factors have been taken into account:

- Crew decrease
- Insurance cost decrease
- Maintenance cost decrease
- Safety improvement
- ATOMOS platform cost
- Non-ATOMOS equipment cost
- Interest rate.

The variation range of these parameters is given in Table 10. Sensitivity analysis was not implemented for the cabling and extra cost categories because these two factors were not included in the main CBA assessment. These percentages are linked to the corresponding data applied to the initial cost benefit and are in a position to clarify various aspects of the problem.

Table 10 Sensitivity analysis variation of the factors chosen for the net present value approach

	Sensitivity Coefficients	Variation (%)
Benefits	Crew decreasing	50–150
	Insurance cost decreasing	50–150
	Safety improvement	50–150
	Maintenance cost decreasing	50–150
Costs	ATOMOS platform	50–150
	Non-ATOMOS	50–150
	Cabling	Not applicable
	Extra	Not applicable
I	Interest rate	50–150

Table 11 and Fig. 6 give the results (NPV) of the sensitivity analysis for a 15-year time period. As the gradient of a selected factor reveals its importance in the described procedure, one sees easily the most significant ones. In general, sensitivity analysis indicated that investment shows an increased sensitivity to the factors of crew cost decrease, ATOMOS platform cost, and interest rate. In fact, crew changes are the determining factor as far as NPV is con-

Table 11 Results of the sensitivity analysis for a 15-year time period

	Sensitivity Factor Variation	−50%	−25%	0%	25%	50%
NPV_{15} (million €)	Crew decreasing	−0.148	0.377	0.901	1.426	1.950
	Insurance cost decreasing	0.899	0.900	0.901	0.902	0.903
	Maintenance cost decreasing	0.802	0.852	0.901	0.951	1.000
	Safety improvement	0.830	0.866	0.901	0.937	0.972
	ATOMOS platform	1.639	1.270	0.901	0.532	0.164
	Non-ATOMOS	0.934	0.918	0.901	0.885	0.869
	Cabling			Not applicable		
	Extra cost			Not applicable		
	Interest rate	1.576	1.201	0.901	0.660	0.464
	Worst scenario	−0.148				
	Optimum scenario					1.950

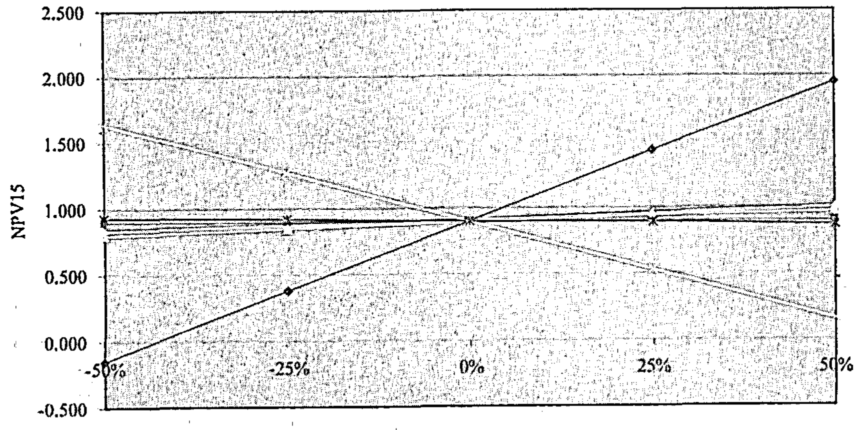

Fig 6 Results of the sensitivity analysis for a 15-year time period

cerned. This means that the NPV method takes mainly into account the benefits resulting from the recorded crew decrease. Additionally, a crucial factor for the feasibility of the retrofit is the ATOMOS platform cost. Finally, the importance of the interest rate (value of money) for long investment horizons should be taken seriously into consideration.

These results seem reasonable. Furthermore, the rest of the parameters only slightly influence the profitability of the specific ATOMOS retrofit. It is also expected that on a longer horizon (e.g., 20 years), the crew cost decrease, ATOMOS platform cost, and interest rate factors are even more central to the efficiency of the investment scheme (ATOMOS retrofit) vis-à-vis the remaining parameters. Because the method also takes into account salary increase with time, crew cost decrease is expected to influence the investment profitability positively to an even greater degree. Thus, in the best-case scenario, that is, when crew cost decrease presents its highest value, the results indicate that the ATOMOS retrofit investment is worth undertaking. This is not so in the worst-case scenario, as then the NPV turns negative. However, it can be concluded overall that the specific investment is profitable for the overwhelming majority of possible scenarios.

Conclusions

A detailed CBA of a retrofit of the ATOMOS technologies on board icebreaker *Frej* was presented in the context of this paper. Even though this analysis was applied to a specific vessel, the general method has a much wider applicability. In fact, one of the products of the ATOMOS IV project has been the Retrofit Strategy Tool, a tool that can guide the owner of any vessel through the steps necessary to evaluate a retrofit in terms of costs and benefits. After accurately determining the relationship between the cost and benefit aspects, a CBA was implemented in order to assess the most basic advantages and disadvantages of the suggested retrofitting action, in monetary terms. A two-step approach was adopted. The first step was to define any possible impacts of the major categories of the ship's operational aggregate costs. This could actually be done in a straightforward manner without taking into consideration any further details. The second step was to examine the various basic components of these categories. At this level, the analysis was additionally focused on the correlations between all the components of each of the above categories. In fact, this was an effort that needed serious data feedback from all parties involved. It could not be done with fractional information, because it covered numerous detailed parts of cost handling, such as additional crew training, reduced crew number, larger effective trip numbers, and so forth. This also led us to adapt the methodology accordingly as well as to conclude an independent research project, in order to retrieve all the required but initially unavailable information.

Several criteria were established according to which the retrofit should be judged, namely, the NPV, the IRR, and PBP. The implementation of the aforementioned criteria showed that in a relatively satisfactory time period (in about 6 years from the moment of the ATOMOS retrofit) the investment becomes favorable for the ship owner of *Frej*. Hence, and on the assumption that the input data provided or otherwise estimated are correct, the analysis shows that there really was little reason for the ship owner to resist fitting the new technologies on board the *Frej*, because the increased safety and efficiency easily justify the investment cost.

More specifically, the three most important factors of uncertainty from the list of parameters are the benefits from the crew decreasing, the ATOMOS platform cost, and the interest rate, which plays a key role, as shown by the subsequent sensitivity analysis. The remaining variables seem to play an unimportant role in the context of formulating the proper financial correlations.

Additionally, it should be noted that the results arising from the application of the NPV criterion and the subsequent sensitivity analysis should be more reliable than those arising from the remaining two methodologies (IRR and PBP). The additional two criteria have been included in this paper in order to present a more comprehensive approach. However, all selected criteria converge more or less to generally positive results concerning the value of the examined investment (ATOMOS retrofit). This is justified from the time period that seems to be sufficient for a positive outcome of the specific investment. It will take about 6 years for *Frej* to start collecting benefits from the ATOMOS retrofit.

In the future it should be interesting to implement such a methodology on a less specialized vessel, a feat that is in theory straightforward. This would enable assessment of costs and benefits of the generic ATOMOS platform and its applicability on regular commercial vessels.

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