Integrated navigation, with the use of Kalman filter and integrated procedures in modern navigation

Dramane P. Cissoko

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INTEGRATED NAVIGATION, WITH THE USE OF KALMAN FILTER
AND INTEGRATED PROCEDURES IN MODERN NAVIGATION

by

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Senegal

A paper submitted to the Faculty of the World Maritime University
in partial satisfaction of the requirements for the award of a

MASTER OF SCIENCE DEGREE

in

MARITIME EDUCATION AND TRAINING (NAUTICAL).

The contents of this paper reflect my personal views and are not
necessarily endorsed by the UNIVERSITY.

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"AU NOM DE DIEU

LE CLEMENT

LE MISERICORDIEUX."

TO MY FATHER BOUBACAR AND MY UNCLE MASY.

TO MY SYSTER AWÀ AND MY BROTHER DAO COUMBA DIOP.
I am extremely grateful to God, the Almighty for being at the World Maritime University (WMU) in Malmo. It is a privilege to be at the WMU, the meeting place of most eminent people belonging to the maritime field...

My profound gratitude goes to Mr. John Hadjipateras for sponsoring me through the Markos And Angelikis Lyra Scholarship.

I would like to express my deepest gratitude to those who help me attend the course i.e:

- Henry Diouf, Director Of The Department Of The "Marine Marchande", Dakar,

- Pierre Sarr, a friend and former graduate of the WMU, Chief Division at the Department Of The "Marine Marchande", Dakar,

- Ambassador B. Zagorin, Senior Adviser to the Chancellor International Maritime Organization (IMO),

- Cynthia Mrigate, Assistant to the Rector at the WMU.

The preparation and successful completion of this paper have been made possible thanks to the help of many people, whom I am deeply indebted to for providing me with the guidance, relevant information, material and encouragement.
I would like to express my warmest and deepest thanks to Gunter Zade, my course Professor who has endeavoured during two years to improve my knowledge and skills in navigation and related matters...

I am very grateful to Professor A. Yakushenkov my co-assessor, for the choice of the topic, material and guidance when realising this thesis.

The invaluable assistance, guidance, advise and continuous encouragement of my indefatigable assessor Professor J.H. Mulders stimulated me to overcome the difficulties met in preparing this paper. My heartfelt thanks and gratitude go to Him. This thesis would not be acceptable without Professor Mulders' knowledge and experience.
I also extend my special appreciation and sincere gratitude to my assessor, lecturer Hans Van Walen and lecturer Stephen J. Cross for their assistance, availability and kindness.

I would like to express my particular thanks and gratitude to:

- Mr. Richard Poisson and all the members of his department,

- Clive Cole, Alison Hove, Mrs. Lakshmie, Ranni Verne, Inger Sund Battista, Sue Helene M., B. Wagner, Mats Johansson, Elizabeth Lindh, Solveig Anelli and the whole WMU staff.
- I extend the same gratitude to all visiting Professors, especially Mr. M. Jurdzinski, H. Kaps, S. Kastner, B. Berk- ing, F. Arbeider, Y. Draaisma, J. Froese and all the distin- guished resident Professors for their dedicated and knowledgeable lectures during the course,

- My classmates, among the best I ever had.

- Moustapha Sene, Senior Training Adviser to the "Minis- tre De L’Equipement", Dakar,

- Moustapha Mbengue, at the "MINISTERE DE LA COOPERATION", Dakar,

Finally, I acknowledge, with my deepest sincerity and from the bottom of my heart the generosity, kindness and love of Kith Arman, one of the best ladies I ever met.
Shipping is the servant of world trade and as long as the latter will exist, ships will be engaged in commercial activities among different nations.

Being of international character by nature, shipping has generated a variety of concerns and problems involving Governments/shipowners and all the maritime community...

To improve efficiency hence profitability and competitiveness; to fulfill I.M.O. standards and to better adapt themselves to the new needs of the maritime industry; that was the challenge which the shipbuilding industry and nav-aid manufactures had to overcome during the last decade. These objectives had to be achieved through modern technology application... This factor, combined with other economical reasons have generated lots of new developments and changes in the way of operating vessels...

Nowadays, the "State-Of-Art" in its modern meaning is fundamentally based upon integration, remote control systems and high level of automation etc.

The Challenge faced by the navigator is to appreciate the advantages and drawbacks of such technology, in order to improve safety at sea as well as efficiency and effectiveness, the sole criteria of performance in this shipping world of fierce competition.
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CHAPTER ONE

INTEGRATED NAVIGATION

1. INTRODUCTION

With I.M.O. Resolution A-529 pertaining to accuracy of ship's running co-ordinate determination, the standards laid down for improving navigation safety have increased.

The requirements have grown more stringent because of the number of navigation casualties and their negative and/or costly impact on the environment, while the yearly number of lives lost shows an uncomfortable increase. (See Fig. 1 and 2, page 3 and 4) In this respect, two factors have to be considered i.e:
- human element, and
- equipment itself.
As a matter of fact, casualties are caused by the human factor if the machine is not involved.

As for shipping companies, the reduction of running costs has become more acute than ever before. As a matter of fact, economic factors have imposed strong pressure for more accuracy in navigation which in turn would not only increase safety but also reduce steaming time.

For these reasons, J.F. ROEBER (1) points that "today, accuracy well above that necessary to get you generally near your destination assumes economic importance."

-1-
The advent of digital processing of navigation information has opened possibilities to process navigation data in a manner (through digital filters) that an improved accuracy can be obtained which is much better than was believed to be attainable some decades ago. This effect especially can be realized through so-called "Integrated Navigation Systems."

Another consequence derived from the application of modern and advanced technology is the reduction of human tasks and/or actions on the bridge through so-called "Integrated Navigation Procedures".

It is worth noting that both above mentioned effects are bounded through identical phrasing by the prefix "Integrated".

It should also be stressed that accurate track keeping in modern navigation should be regarded as an ultimate purpose of integrated navigation. The principle of position fixing, which plays an important role in navigation is only a part of a whole control system including the application of filtering techniques for improving ship's hydrodynamics.
Fig. 1 Merchant ships casualties during the period 1977-1987
<table>
<thead>
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<tr>
<td>Foundered</td>
<td>523</td>
<td>428</td>
<td>440</td>
<td>317</td>
<td>570</td>
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<tr>
<td>Missing</td>
<td>78</td>
<td>85</td>
<td>32</td>
<td>68</td>
<td>0</td>
</tr>
<tr>
<td>Fire/Explosion</td>
<td>29</td>
<td>29</td>
<td>94</td>
<td>51</td>
<td>53</td>
</tr>
<tr>
<td>Collision</td>
<td>3,156</td>
<td>448</td>
<td>14</td>
<td>54</td>
<td>25</td>
</tr>
<tr>
<td>Contact</td>
<td>0</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Wrecked/Stranded</td>
<td>34</td>
<td>27</td>
<td>9</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>Lost, etc.</td>
<td>21</td>
<td>43</td>
<td>27</td>
<td>28</td>
<td>8</td>
</tr>
<tr>
<td><strong>TOTAL LIVES</strong></td>
<td><strong>3,841</strong></td>
<td><strong>1,067</strong></td>
<td><strong>619</strong></td>
<td><strong>525</strong></td>
<td><strong>671</strong></td>
</tr>
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**Fig. 2** (a)(b) number of ships lost compared to lives lost during the period 1983-1987
CHAPTER TWO

PURPOSES OF INTEGRATED NAVIGATION

2.1. INTEGRATED NAVIGATION SYSTEMS

Marine casualties during the last 2 decades have proved that accurate navigation cannot merely lie upon available stand alone systems which are generally radionavigation navaids.

It is a known fact that navaid measurements are characterised by systematic (i.e. fixed) and unpredictable or random errors which are inherent to any navigational system.

If LORAN C is not taken into account because of its coverage strictly limited to the northern hemisphere, OMEGA and TRANSIT do not satisfy the navigator’s need as regards accuracy and availability. Their performance for coastal navigation and manoeuvres within confined waters is not satisfactory.

As far as DECCA is concerned, the system in general offers sufficient accuracy for coastal navigation and approaches to ports. That is why Michael J. Dove and Keith Miller (2) observe that "considering all the navigation aids available to, or likely to be available to the navigator within the immediate future, only DECCA will give a fix accuracy of better than 100 meters, and this will be attained dur-
This point stresses the inaccuracy of the system with the increase of range and during nighttime. In addition, a DECCA chain covers only a relatively small area.

As for the Global Positioning System (G.P.S.), mariners should not exult too much because of the policy adopted by the United States Department Of Defense (U.S.D.O.D.) aimed at degrading the accuracy of the system for civil users.

As a matter of fact, the selective availability technique (S/A) is especially intended to limit the accuracy of the Global Positioning System (G.P.S.) for politico-military reasons. Despite that fact, M.J.Dove, R.S.Burns, and J.L Evison (3) point that "with the exception of G.P.S., there is no single system which will meet the requirements for continuous world-wide coverage with the required accuracy". In addition, Differential G.P.S. or G.P.S. integrated with another radionavigation system may be put in service and may probably enhance the system's accuracy for civil navigation.

In West Europe, LORAN C has been proposed for that purpose at the Conference of the International Association Of Lighthouse Authorities (I.A.L.A) held in London in March 1987.

All the navaids above cited if available, are disseminated here and there on traditional bridges for backing up each other and so improve reliability of navigation. But unfortunately, this does not improve accuracy of navigation.

As for improvement of position accuracy, an advanced pra-
ctice is to process information from, for instance G.P.S. and LORAN C. By "optimal mixing" of both navigation information signals, an accuracy can be obtained which is better than the accuracies of each system if they were stand alone systems.

2.2. INTEGRATED NAVIGATION PROCEDURES

Another serious problem in navigation is connected to the "explosion of information" on the bridge, when relevant data cannot be processed properly by the officer of the watch.

The reflexion put forward by J.B. Carr (4) better explains that situation. He says in substance, that "the data available to the officer is in some cases changing with a speed and complexity that taxes the human brain beyond its limits, or alternatively the critical motions are too small to be appreciated by human sensory perception."

A case in point is the difficulty met by the navigator to assess the true motion of a distant target by visual means only compared to a radar performance, or a rate-gyro or rate of turn indicator which is not only much faster than the human eye in detecting and displaying a tendency of turning, but also by far superior in maintaining a certain angular velocity.

But one can also imagine a human radar operator trying to handle 10 targets on the screen, and to monitor his own vessel at the same time...
In consideration of these facts, integrated systems have been developed for more precise and accurate navigation of which the benefit would be a gain in safety and efficiency. And the same facts show also that integrated navigation is not only limited to position fixing.

Before its advent, all the data supplied by various navigational equipment/instruments were not only "scattered" throughout the bridge but they were also subject to "manual-mental" processing and mental "integration" in order to get the best output from the available information.

The "processing" and "integration" tasks were performed by the navigator who stood as human co-ordinator between various sources of information due to the fact they were not designated to interface with each other.

It is obvious that this represents excess workload in today's maritime environment. Furthermore, the "decision making" process is hampered and this fact may greatly increase the probability of collisions or groundings whenever a piece of information has been overlooked or misinterpreted.

Integrated navigation in the sense of combining the inputs from several systems, is therefore aiming at reducing the workload as well as backing up the officer of the watch in the "decision making" process.

A good example of this kind of integration is true motion radar which has been extended to ARPA. True motion radar has been the first step towards integration, although this concept of integration deals with the integration of the
environmental motion through the radar picture combined with the actual motion of the vessel itself.
CHAPTER THREE

CONCEPT OF INTEGRATED NAVIGATION

3.1. CONCEPT OF INTEGRATED NAVIGATION SYSTEMS

Single system measurements are corrupted by errors and concerning these deficiencies, M.J. Dove, R.S. Burns and J.L Evison (3) observe that "if it is assumed that systematic (i.e. fixed) errors can be allowed for, then one of the requirements in an integrated system is to minimize in some way the random errors."

Definition: an integrated navigation system is a configuration which optimally combines (integrates) available information from two or more sub-systems in order to obtain the best estimates of ship's navigational parameters i.e.: - heading, - speed, - position, - drift, - engine revolutions, etc.

A "simple integrated navigation" system gathers the data from two/or more stand alone systems and, either produces an alarm state if the separate variables are in dispute or determines which of them should be the most accurate and presents that as an integrated output of the whole system.
The failures of such systems concerning accuracy of navigation have prompted great developments towards integrated systems with the use of filters.

3.1.1. COMPLEMENTARY "INTEGRATED NAVIGATION SYSTEMS"

Unlike "simple integrated navigation systems" which are not designated to gather different kind of information to support each other, complementary "integrated navigation systems" are measuring identical navigational quantities and are fitted with filters.

This development allows them to produce the most accurate estimate of the measured variable(s) presented as an integrated output of the whole. An example of integration with the use of "Kalman Filter Technique" will be dealt with in chapter 5.

The principle of complementary integrated navigation is not brand new but was already exploited a long time ago when, e.g. an astronomical fix and Dead Reckoning position were weighted so as to produce a Most Probable Position (M.P.P) which was situated somewhere between the DR and the astronomical fix. (see fig. 3, page 12)
Fig. 3 Weighted position from an astronomical fix and Dead Reckoning
3.1.2. KALMAN FILTERS IN INTEGRATED NAVIGATION

INTRODUCTION

Filtering random stationary signals first has been tackled by the scientist N. Wiener during the late 1940's. Unfortunately, Wiener's research concerning filtering techniques was not backed up by advanced technology, especially in processing errors' information. In addition, his theory only dealt with random stationary signals.

After Wiener, lots of studies and research were carried out towards radiosignals' filtering in order to "clean" them from various disturbances (i.e.: random errors) introduced in the transmission path, different circuitries, etc., and improve them at the receiver's level.

However, filtering techniques have been extended to other types of signals which were not only stationary.

The theory has been later dealt with by Kalman and Bucy who came up with a successful and concrete technique of filtering sampled data during the 1960's.

Their work has been carried out towards a known field related to random errors' behaviour not only in radiosignals, but also in other measurements where unpredictable or random errors are present.
3.1.3. KALMAN'S AND BUCY'S DISCOVERY

These two scientists have successfully exploited the characteristic and already known fact (discovered by Gauss), that errors within a large number of repeated measurements arising in nature, industry as well as research mostly obey the "rule" of normal distribution (or Gaussian distribution).

Mathematically, the formula of a normal distribution curve is given by the relation:

\[ f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x-\bar{x})^2}{2\sigma^2}\right) \]

where:
- \( x \) - measured variable
- \( \bar{x} \) - mean value of the variable
- \( \sigma \) - standard deviation of errors
- \( \sigma^2 \) - variance of errors
- \( f(x) \) - normal distribution function
- \( \pi \) - mathematical constant (\( \pi = 3.14 \))

(See fig. 4, page 15 - a normal distribution curve.)
Fig. 4 normal distribution curve
But, "a normal distribution of random errors implies the definition of these errors in terms of standard deviation, and hence variance."(4)

Remarkable was the discovery made by Kalman and Bucy who understood the correlation between the accuracy of obtained measurements and the magnitude of random errors' variance. As a matter of fact, their powerful filtering technique is based upon the criteria of minimizing the variance of errors corrupting the measurements.

Therefore, "Kalman-Bucy" filter can truly be considered as a "minimum-variance-filter", which produces its own statistics. Their filtering technique has also found application in navigation where the presence of random errors affects the quality of measurements. However, it should be mentioned that not all navigational errors are subject to normal distribution. Nevertheless, when errors of which the distribution is not normal are combined, the final result obey the rule of normal distribution.

3.1.4 CONCEPT OF KALMAN FILTER TECHNIQUE

Kalman Filter Technique is based upon the optimal combination of noise corrupted measurements of a random process in order to obtain best estimates of the variable or state which governs a system, having previous knowledge or a priori information about the quality of measurements which is given through the variance of corrupting sources and the model of the undisturbed signal.
The process of filtering consists of ascribing weighting coefficients to previous and new information or data from the same system, and to derive minimum variance of the improved estimate after optimal combination of the measurements.

Extremely important in filtering is the fact that the pattern of various disturbances affecting their measurements should not, any time be correlated. This means that the disturbances should be independent from each other. This condition is important due to the fact that the filter calculates the optimal gain under the assumption of minimizing the sum of the variances of uncorrelated disturbances. (See fig. 5, page 18)

Therefore, the choice of equipment for integration plays an extremely important role within integrated navigation systems. An example of integration can be a position fixing system such as LORAN C and Dead Reckoning. Within this configuration, the errors corrupting LORAN C measurements are totally independent of errors in the Dead Reckoning method. The integration of an electromagnetic log with a Doppler log is another example where errors within the two systems are uncorrelated.

The principle of data processing will be dealt with using a One State Kalman Filter which, for simplification purposes will not need any matrix manipulation inherent to the derivation of Kalman Filter’s algorithm with system’s dynamics. However, a One State Kalman Filter is the basis for understanding the Kalman Multi-Dimensional dynamic system equations and/or Extended Kalman Filter.
As the Kalman Filter operates according to the "minimum-variance" principle, Integrated Complementary systems will be first dealt with in chapter 4.

Fig. 5 example of uncorrelated disturbances affecting 2 signals
3.2. INTEGRATED NAVIGATION PROCEDURES AND BRIDGE AUTOMATION

Operating a ship at peak efficiency with the best available techniques steps beyond the principle of nav aids' integration only.

It implies full integration of all ship functions using e.g. local area networks and distributing processing to improve the speed and reliability of the system. (See fig. 6 (a) page 20 and 6 (b) page 21)

This concept encompasses the automatic measurement and integration of all available data for navigation and the monitoring of ship's performance and general condition.

Total integration also suggests shifting several routine tasks from the officer on duty to automatic controllers and warning systems in order to reduce the workload to a minimum.

The bridge being the center of the system is so designed that 5 main tasks can be performed i.e.:
- navigation: continuous position fixing, continuous course and track keeping,
- communication: information exchange with ships and shore based stations,
- collision avoidance: a powerful part of a fully integrated navigation system with extensive use of ARPA,
- monitoring of ship stability, hull strength, engine performance, cargo parameters,
- data registration: ship's and environmental data, etc.
Fig. 6 (a) System Integration Network (example 1)
Fig. 6 (b) System Integration Network (example 2)
The above mentioned tasks are fulfilled according to the modular concept in which each data source can be regarded as self controlled or as part of whole bridge automation with a common bus connection.

The advantage of this system is the existence of sub-systems which are linked to each other and, its flexibility due to the fact that some other data sources can easily be adapted, or even improvements carried out.

In ship handling automation, the principles of heading performance is of utmost importance within this configuration i.e:
- straight course keeping,
- changing to a new course, and
- turning at prescribed rate of turn (or radius of turn).

Their understanding requires knowledge of the ship equations of motion (a simple, but for certain types of conventional ships, usable model is described by the "First Order Nomoto Model: Tdr/dt + r = K\delta + k'f(t)) and applied control laws (i.e.: Proportional-P., Proportional Differential-P.D., Proportional Integral Differential-P.I.D. controls) where:

\[ T \] - ship's time constant
\[ r \] - ship's angular velocity
\[ K \] - ship's turning ability index
\[ \delta \] - rudder angle
\[ k' \] - parameter depending on K
\[ f(t) \] - all acting disturbances
These principles are dealt with in some textbooks. Also, an article written by Dr. Asinovsky (5) on ship manoeuvrability is of great interest because it studies, not only some physical aspects of ship motion, but also selects "objective criteria which can be equally acceptable to naval architects and navigators."

Therefore, it should be borne in mind that integrated navigation without proper knowledge of ship behaviour does not make any sense from a navigational point of view. For, what is the benefit of accurate position fixing — which is extremely important in navigation — when the vessel is not able to follow its pre-planned course or track?

This is one of the reasons why navigation should not be considered as separate different tasks but as a "package."(6)

A decisive step has been made when the shipbuilding industry understood that better control quality of ship heading performance is the prime support for position fixing. Optimization of T and K values according to ship types, and controller gains depending on specific external conditions (wind, current, etc.) has greatly improved course keeping on ocean passages and accuracy of coastal and narrow waters navigation.

The field of automatic and adaptive steering control has seen important developments during the last decade. As regards, it is worthwhile mentioning Kockum's Steer-master 2000 built by the shipbuilding firm "Kockum" (Malmö-Sweden) which gives appreciable results in practice.
There are other tasks of the navigator which are not dealt with herein but which are performed from the automated bridge such as:
- optimization of engine revolutions,
- monitoring of the engine,
- monitoring of ship's velocity, angle and period of roll in order to prevent from resonance of which the consequences may be disastrous,
- communication patterns,
- cargo data monitoring, etc.

3.2.1. INTEGRATED NAVIGATION PROCEDURES EXAMPLES

ELECTRONIC SEACHART-RADAR

Digital processing of information has also found extensive application in charts production. This new development, which requires high technology has brought about the concept of the electronic seachart which nowadays, represents the output of a complex integrated navigation procedure or information system on board modern vessels.

Producing an electronic seachart can be done by scanning a normal paper chart and displaying all its information in a raster mode.

Another method currently used for the same purpose consists of building a data base made of digitised "lines" and "points" information acquired from a normal paper chart and transforming them from raster to vector display.
All those information have to be converted into digital data and stored. This process enables to build electronic seacharts' data bases which are generally very comprehensive, compatible and can provide continuous information.

This feature enables the selection and display of relevant areas, desired scales, and basic information i.e.: coast lines, buoys, navigational dangers, etc. Moreover, the electronic data base can provide additional selectable information set out in layers. This can be depth, tides, currents, pilot stations, already planned courses, way points, etc.

The benefits derived from an accurate Electronic Chart Display Information System (ECDIS), which is a data file of an Electronic Navigation Chart (ENC) are considerable.

As regards, it is worthpointing that the interface "radar-chart" has been made possible thanks to the emergence of the electronic seachart and this development has brought about new opportunities in the "State-Of-Art".

But the best utilization of the electronic seachart will be achieved through its integration with ARPA. As a matter of fact, the combination of the two systems will represent a totally new concept in navigation, a concept which has integrated an "anti-collision device with an anti-grounding system". (7)

Depending upon the accuracy of the positioning system(s) available on board a vessel using an electronic chart display equipment (ECDE), there will be, within the interface "ARPA-electronic chart" (or "radar-electronic chart"), a continuous checking of one system upon the other. This
possibility will simplify the identification of geographical hazards and aids to navigation. Furthermore, it will enable continuous fixes (when ARPA or radar are used for position fixing) and automatic tracking of targets on a chart using the same display.

Taking maximum advantage of this configuration will require an accurate position fixing system without which an electronic seachart is not reliable to fulfill alone, the requirements under Chapter 5, Regulation 20 of the Safety Of Life At Sea 1974 (SOLAS 74) Convention.

The role which the electronic seachart can play in modern navigation is therefore dependent on the quality of information acquired from position fixing devices. Here again, good integration is the key to provide accurate navigation data (i.e.: position) to the system.

Sophisticated electronic seacharts, available in the future will contain a great quantity of integrated information that could be needed during a voyage. The possibility to acquire sailing directions, notices to mariners etc. at the same display will tremendously decrease the "human workload".

The prospective of automatic correction of electronic seacharts via satellite (INMARSAT for instance) will greatly reduce the workload from the officer of the watch and increase the safety of navigation. All these new developments will represent invaluable tools for passage planning and their proper use may greatly improve safety of navigation and efficiency of ships operation.
"Introduction of the electronic seachart as an integrated information system will have far-reaching consequences not only for navigation, but also for general ship-handling, the man on the bridge and shore organizations." (B)

However, electronic seacharts should not be overestimated. Apart from their accuracy which should, at least be equal if not better than the paper charts', a power failure switches them off and, as long as the failure will remain the electronic seacharts would not be available.

Another problem is related to their overloading. As a matter of fact, too much information is available to the user who will have to select the relevant data. Here also, the choice of information beares an extremely important character due to the fact it has, not only to be selected but also interpreted accordingly.

Moreover, any wrong data present in the display may lead to a desaster. This may happen when the software is not correct or errors present within the data base, or even when the system would not properly function.

But a serious problem will certainly be connected to the user's skills and ability to adequately "read" the electronic seachart in a professional way. Therefore, only training and experience will represent the criteria for taking maximum advantage of it.

Last, but not the least is the problem of its updating which should be solved through an international agreement.
3.2.2. THE ONE MAN-BRIDGE

The ONE-MAN-BRIDGE, although self-explanatory, refers to the sole presence of only one person on the bridge (the officer on duty) for keeping a lookout, monitoring, and processing all the information provided to him during a normal period of watch. (see fig.7 page 30)

Obviously, this differs from the traditional and conventional way of operating ships being practised by the largest number of shipping companies.

It is in fact a brand new concept in itself and, its implementation in Japan and some West European Countries represents an innovation which carries new perspectives in the field of ships' operation and for these reasons, the matter should be considered.

ONE-MAN-BRIDGE has been made possible by the use of advanced electronics, computing techniques with digital display and a high level of automation on board vessels.

This development was promoted for the sake of offsetting expenditures by long-term cost reductions which would result from lower manning levels. In this respect, the combination of the cited technical factors (i.e.: electronics, computing techniques and automation) has enabled the rationalization of operations as well as centralization of control and monitoring of navigation including collision avoidance, engine and hull performance, cargo data control, communications, etc.
In other words, functional areas have been identified after various studies and this has led to the reduction of the number of functions and centralization of essential displays. The integration and/or automation of those functions combined with the possibility to have a centralized display (graphic and alphanumerical) of all the relevant information has enabled the safe operation of a vessel from the bridge to be performed by a stand alone officer during the watch.

In this configuration, the bridge as "ship operation center" is the focal point of "physically and functionally" optimized integrated navigation systems and procedures. Efforts have been carried out to "facilitate a high level of system redundancy consistent with improved levels of safety and reliability at all stages of operation" (9), and various alarm systems detecting faults and/or deficiencies.

For a bridge to be on the responsibility of only one man, ergonomics (human engineering) has been extensively used to help design the modern bridge and its equipment/instruments. The latter are such designed and developed that they can easily and efficiently be operated by the navigator who will perform the watch mostly in a seated position from which the view is panoramic. (See Fig. 8 (a) and 8 (b) page 31 and 32)
Fig. 7 Tasks of a One-Man-Bridge
Fig. 8 (a) Integrated Bridge with panoramic windows
Fig. 8 (b) Integrated Bridge For a Single Man Watch
Fig. 8 (c) Example of centralised display of navigation information
Further improvements have been directed towards recreation facilities in order to provide much more job satisfaction...

Although very sophisticated equipment and instruments support this concept, the final decision is left to the man in his interface with such advanced technology.

One should nowadays agree that the One-Man-Bridge will not die in its state of projects and/or trials. The International Maritime Organization (I.M.O) through the Maritime Safety Committee (M.S.C) presently is thoroughly investigating the subject in order to find a reasonable implementation of "single watch" on board vessels. But one can already foresee the outcome because of powerful economic considerations and a just logical step towards progress with the support of high technology.

However, this problem needs further investigation from psycho and physiological point of view.
CHAPTER FOUR

PRINCIPLE OF DATA PROCESSING IN AN INTEGRATED COMPLEMENTARY SYSTEM

4.1. ERROR EQUATION

Fig. 9 Realization of a dual integrated navigation system
Where:

$x$ - uncorrupted quantity

$S_1$ - errors affecting measurements with Navaid 1

$S_2$ - errors affecting measurements with Navaid 2

$X_1$ - measured data Navaid 1

$X_2$ - measured data Navaid 2

$X_i$ - optimal estimate

$K$ - weighting factor or filter gain ($1 < K < 1$)

Let us consider that:

\[ x + S_1 = X_1 \]

and

\[ x + S_2 = X_2 \]

The derivation of an optimal filter algorithm requires the fulfilment of some conditions in order to make possible the filtering process i.e.:

- the filter should hold information about the variance of the disturbing sources, and

- $S_1$ and $S_2$ should be independent.

The general form of an improved estimate or smoothed estimate is given by the formula:

\[ X_i = K(X_1+S_1) + (1-K)(X_2+S_2) \]
from which it is calculated that the next figure (Fig. 10) is equivalent to the original system.

Fig. 10
\[ X_i = X + K S_1 + (1-K) S_2 \]

\[ X + S = X + K S_1 + (1-K) S_2 \]

\[ S = K S_1 + (1-K) S_2 \]  \hspace{1cm} (1)

Equation (1) represents the error equation.

The principle of integration in this example lies upon the fact that the 2 navaids are measuring the same navigation quantity. In addition, errors’ S1 and S2 behaviours are statistically independent.

However, only the fact that errors S1 and S2 should be totally independent does not solve the problem of filtering. As a matter of fact, the errors affecting the measurements are random and therefore not known. If their magnitudes were known, the filtering process would have been limited to a simple algebraic sum of the measurements and errors in order to obtain the best estimate of the variable.

The errors S1 and S2 are not known by the filter. However, it holds statistical information characterizing each of them and which describes the variance of the different errors present in the system. In other words, the filter holds a built-in error model which defines the statistical behaviour of the different errors. In the process of filtering therefore, the errors S1 and S2 will be dealt with only through their respective variances.

Let us assume that the measurement X1 is corrupted with variance \( \sigma_{x1}^2 \) and the measurement X2 is performed with variance \( \sigma_{x2}^2 \).
From statistics,

\[ \text{Var} X_i = K \cdot \text{E}(X_1 - \text{E}(X_1)) + (1-K) \cdot \text{E}(X_2 - \text{E}(X_2)) \]

\[ \text{Var} S = K \cdot \text{E}(S_1 - \text{E}(S_1)) + (1-K) \cdot \text{E}(S_2 - \text{E}(S_2)) \quad (2) \]

but, from the previous conditions it follows that

\[ \text{E}(S_1 - \text{E}(S_1)) = \text{Var} S_1 = \sigma_s^2 \]

and

\[ \text{E}(S_2 - \text{E}(S_2)) = \text{Var} S_2 = \sigma_s^2 \]

thus

\[ \text{Var} S = K \cdot \text{Var} S_1 + (1-K) \cdot \text{Var} S_2 \quad (3) \]

substituting

\[ \text{Var} S \text{ by } \sigma_s^2 \]

\[ \text{Var} S_1 \text{ by } \sigma_s^2 \]

and

\[ \text{Var} S_2 \text{ by } \sigma_s^2 \]

equation (3) becomes

\[ \sigma_s^2 = K \cdot \sigma_s^2 + (1-K) \cdot \sigma_s^2 \quad (4) \]
4.2. SELECTION OF K FACTOR

The variance of the smoothed or improved estimate is a function of the weighting coefficient $K$ and can be written $f(K)$ taking into consideration that $S1$ and $S2$ are independent.

Let us substitute $\sigma_i^4$ by $f(K)$ in equation (4)

$$f(K) = K \sigma^4_1 + (1-K) \sigma^4_2$$

The function $f(K)$ reaches minimum when

$$\frac{df}{dK} = 0$$

this means when

$$d(\sigma^4_2 K + (1-K) \sigma^4_1) = 0$$

thus

$$\frac{d(\sigma^4_2 K)}{dK} + \frac{d((1-K) \sigma^4_1)}{dK} = 0$$

$$-2\sigma^4_2 (1-K) + 2\sigma^4_2 K = 0$$

$$\sigma^4_2 K = \sigma^4_2 (1-K)$$

$$\sigma^4_2 K = \sigma^4_2 - \sigma^4_2 K$$

$$\sigma^4_2 K + \sigma^4_2 K = \sigma^4$$

thus

$$K (\sigma^4_2 + \sigma^4_1) = \sigma^4_1$$

-40-
Since $K$ represents the minimum of the function, it is called optimum weighting coefficient and is written $\hat{K}$. Therefore, equation (6) can be written

$$K = \frac{\alpha_i}{\sigma_i^2 + \sigma_j^2}$$ \hspace{1cm} (6)

and

$$1 - K = \frac{\sigma_j^2}{\sigma_i^2 + \sigma_j^2}$$ \hspace{1cm} (8)

finally equation (4) will read

$$\sigma_j^2 = (1-K)\sigma_i^2 + K\sigma_j^2$$ \hspace{1cm} (4.1)

![Diagram](Fig. 11 variation of $f(K)$)
Fig. 12 Choice of optimal $K = \hat{K}$, with respect to $\sigma_i^l$ and $\sigma^l_j$
4.3. MINIMUM VARIANCE

Having computed the optimum value of the weighting coefficient \( \hat{K} \), equation (2) can be re-written as follows:

\[
\hat{\sigma}_{i} = E \left[ \left( 1 - \hat{K} \right) (S2 - E(S2)) + \hat{K} (S1 - E(S1)) \right] ^{2}
\]

(substituting \( \hat{K} \) by its value in equation (9) one obtains:

\[
\hat{\sigma}_{i} = E \left[ \left( \frac{\sigma_{i}^{l}}{\sigma_{i}^{l} + \sigma_{i}^{s}} \right) (S2 - E(S2)) + \left( \frac{\sigma_{i}^{l}}{\sigma_{i}^{l} + \sigma_{i}^{s}} \right) (S1 - E(S1)) \right] ^{2}
\]

After development one obtains

\[
\hat{\sigma}_{i} = \left[ 1 - \frac{\sigma_{i}^{l}}{\sigma_{i}^{l} + \sigma_{i}^{s}} \right] ^{2} \sigma_{i}^{l} + \left[ \frac{\sigma_{i}^{l}}{\sigma_{i}^{l} + \sigma_{i}^{s}} \right] ^{2} \sigma_{i}^{s}
\]

\[
\hat{\sigma}_{i} = \left( \frac{\sigma_{i}^{l} + \sigma_{i}^{l} - \sigma_{i}^{l}}{\sigma_{i}^{l} + \sigma_{i}^{s}} \right) \sigma_{i}^{l} + \left( \frac{\sigma_{i}^{l}}{\sigma_{i}^{l} + \sigma_{i}^{s}} \right) \sigma_{i}^{s}
\]

\[
\hat{\sigma}_{i} = \frac{\sigma_{i}^{l} \sigma_{i}^{l} + \sigma_{i}^{l} \sigma_{i}^{s}}{(\sigma_{i}^{l} + \sigma_{i}^{s}) \sigma_{i}^{l}}
\]

\[
\hat{\sigma}_{i} = \frac{\sigma_{i}^{l} \sigma_{i}^{l} + \sigma_{i}^{l} \sigma_{i}^{s}}{(\sigma_{i}^{l} + \sigma_{i}^{s}) \sigma_{i}^{l}}
\]
\[
\hat{\sigma}_i = \frac{(\sigma^t + \sigma^v) \sigma^t}{(\sigma^t + \sigma^v)^2}
\]

After simplification one obtains:

\[
\hat{\sigma}_i = \frac{\sigma^t}{\sigma^t + \sigma^v}
\]

Equations (1), (7) and (10) represent the optimal filter equations.

\[
\hat{\sigma}_i = K \sigma^v \text{ or } (1-K) \sigma^t
\]

Inverting equation (10) one obtains:

\[
\frac{1}{\hat{\sigma}_i} = \frac{1}{\sigma^t + \sigma^v} \frac{\sigma^t}{\sigma^t} + \frac{1}{\sigma^v}
\]

After simplification equation (10) becomes:

\[
\frac{1}{\hat{\sigma}_i} = \frac{1}{\sigma^t} + \frac{1}{\sigma^v}
\]

The variance of the smoothed or improved estimate \( X \) has been computed from the optimum weighting coefficient which previously, has been derived from the minimum value of the function \( f(K) \). Due to that, equation (11) can be written
as follows:

\[
\frac{1}{\hat{\sigma}_i^2} = \frac{1}{\sigma_i^2} + \frac{1}{\sigma_a^2} + \frac{1}{\sigma_v^2}
\]  

(12)

where:

\[\hat{\sigma}_i\] - minimum variance of the optimal estimate

The derivation of the minimum variance of the optimal estimate shows that the weighting coefficient \(k\) has been chosen so as the improved estimate has minimum variance and therefore maximum probability of being the actual value of the measurement.

The minimum variance finally computed represents the highest degree of confidence which is held by the system as far as next measurements will be concerned.

The principle of data processing within a Multi-Dimensional Kalman Filter is very similar to One State's. However, it should be mentioned that a Multi-Dimensional Kalman Filter's principle is based upon matrices manipulation because of the fact that many variables e.g. position, North and East component of velocity, angular velocity, heading, accelerations etc. are processed at the same time.

The notion of State Variables, which defines the behaviour of the system should be understood. As a matter of fact, it represents a set of navigational parameters that give full knowledge of a system's behaviour.
In the processing stage, the filter generates covariance matrices which represent the degree of belief of the system. The output of such a system is a smoothed State Variables.
CHAPTER FIVE

THE KALMAN FILTER

5.1 REALIZATION

Fig. 13 Realization of One State Kalman Filter
where:

$X$ - uncorrupted quantity

$X_n$ - initial or current measurement

$S_n$ - error affecting the measured quantity

$\hat{X}_n$ - Kalman Filter gain or weighting factor

$\hat{X}_n$ - improved estimate

$\hat{S}_n$ - minimised error

A One state Kalman Filter (see fig. 13) is connected to a system measuring only one variable which, in order to fulfill the requirements of such a filter should be constant.

In addition, the various errors present in the system are not correlated although there is only one channel allocated to the measurement of a quantity. Therefore, the filter should work in such a way that the measurements are performed with intervals larger than $3\times$ correlation time.

Depending on the system used for that purpose, the correlation time may be short or relatively long. (e.g.: G.P.S: a few seconds whereas DECCA errors have round 15 minutes correlation time.)

If 2 subsequent measurements are denoted $X_1$ and $X_2$ then

$X + \hat{S}_1 = X_1$

$X + \hat{S}_2 = X_2$
For the second measurement, the general form of the improved estimate's equation can be written as follows:

\[ \hat{X}_2 = \hat{X}_1 + K_2(X_2 - \hat{X}_1) \]  \hspace{1cm} (13)

where:

\[ K_2 = \frac{\sigma_i}{\sigma_i + \sigma_s} \]  \hspace{1cm} (14)

and

\[ \sigma_i = (1 - K_2)\sigma_i = K_2 \sigma_s \]  \hspace{1cm} (15)

where:

\[ \sigma_i \] - variance of the improved estimate

Equations (13), (14) and (15) represent the One Dimensional Kalman Filter equation.

The filtering process is based upon the optimal combination of present and all previous measurements performed within the same system in order to obtain the best estimate of a corrupted variable.

The filter assigns optimum weighting coefficients to old and recent measurements from the data source. In this system, the same principles are used for the derivation and selection of the filter gain or weighting factor \( K \) in the integrated system dealt with in Chapter 4.

Equation 4 (Chapter 4) has shown that the different variances are the sole terms used for the computation of \( K \) parameter. In fact, the variance of the different errors affecting the accuracy of the measurements represents the degree of belief or confidence factor of the filter.
Therefore, the weighting coefficient \( K \) is provided to the user as additional level of belief of the system.

5.2. RECURSIVE FEATURE OF THE KALMAN FILTER

The powerful feature of Kalman’s and Bucy’s filtering technique lies upon the fact that the filtering process is extremely dynamic and does not only use fixed parameters for the computation of next improved estimates together with their variances.

The recursive process itself can be summarized in 2 different phases i.e.:
- measurement, and
- measurement update.

In the first phase, there is acquisition of data which are weighted by the filter in the light of the variances of the different errors. From the processed data, an improved estimate is derived which holds minimum variance.

The second phase is based upon the filter’s own statistics or prediction of previous data already improved and recent data or new measurements performed by the system.

At each stage namely, at each new performed measurement, the filter assigns a new or different weighting factor for calculating an improved estimate which will hold minimum variance. The so-calculated variance will be used in the computation of the next smoothed estimate of which the variance will be further decreased or minimised. (See ex-
ample pages 52-56, and fig. 16)

Statistically, this means a larger probability for the improved estimate to be the true value of the measurements. Any new performed measurement will be subject to the same iteration.

Therefore, the process can be understood as a "tendency" to further improve the new estimates by minimising the variances of previous estimates. Basically, one can say that the past is optimally weighted in order to update the present.

All the above described process is referred to as recursive feature of the Kalman Filter.

The general form of the One State Kalman Filter recursive equation can be written as follows:

\[ \hat{x}_n = \hat{x}_{n-1} + K_n (x_n - \hat{x}_{n-1}) \] (see fig. 13, page 47)

\[ K_n = \frac{\hat{\sigma}_{n-1}^2}{\hat{\sigma}_{n-1}^2 + \sigma_d^2} \]

\[ \hat{\sigma}_n = K_n \sigma_d \]

where:

- \( n-1 \) - previous sample
- \( n \) - recent sample
- \( \hat{x} \) - improved estimate
- \( \sigma \) - variance of disturbances
Example: A Kalman Filter in a speed measuring system.
We consider the case that a speed measuring sensor (e.g.,
a Doppler log) provides measured speed $X_n$ to a One State
Kalman Filter. The speed is known to be constant.

The variance of the log error ($\text{var } X_s = \sigma_s^2$) = 0.05 kn.
The first estimate is 17.9 kn and its variance is 0.09 kn.
The further processing is as follows:

\begin{align*}
\hat{X}_1 &= 17.9 \text{ kn} \\
\sigma_1^2 &= \text{var } X_1 = 0.09 \\
\hat{X}_2 &= 19.4 \text{ kn} \\
\sigma_2^2 &= \text{var } X_s = 0.05 \\
\end{align*}

(a) - Calculation of the weighting coefficient (or factor)

\[
K_2 = \frac{\sigma_1^2}{\sigma_1^2 + \sigma_s^2} \\
= \frac{0.09}{0.09 + 0.05} \\
= 0.64 \\
\]

(b) - Calculation of the improved estimate

\[
\hat{X}_2 = \hat{X}_1 + (X_2 - \hat{X}_1)K_2 \\
= 17.9 + (19.4 - 17.9)0.64 \text{ kn} \\
= 18.8 \text{ kn}. \text{ (second estimate)}
\]

(c) - Calculation of the variance of the improved estimate
\[ \sigma_{\hat{x}} = K_{2} \sigma_{x} \]
\[ \sigma_{\hat{x}} = 0.64 \times 0.05 = 0.032 \]
\[ \sigma_{\hat{x}} \text{ variance of the second estimate} \]

(2)

Now when the third measurement is obtained

\[ \hat{x}_2 = 18.8 \text{ kn.} \]
\[ \sigma_{\hat{x}} = \sigma_{\hat{x}_2} = 0.032 \]
\[ \hat{x}_3 = 17.1 \text{ kn.} \]
\[ \sigma_{\hat{x}} = \sigma_{\hat{x}_3} = 0.05 \]

(a)

\[ \hat{x}_3 = \frac{\hat{x}_2}{\sigma_{\hat{x}_2} + \sigma_{\hat{x}_3}} = \frac{18.8}{0.032 + 0.05} = 0.39 \]

(b)

\[ \hat{x}_3 = \hat{x}_2 + (x_3 - \hat{x}_2)K_3 \]
\[ \hat{x}_3 = 18.8 + (17.1 - 18.8)0.39 \]
\[ \hat{x}_3 = 18.13 \text{ kn. (third estimate)} \]

(c)

\[ \sigma_{\hat{x}} = K_{3} \sigma_{x} \]
\[ \sigma_{\hat{x}} = 0.39 \times 0.05 = 0.019 \]
\[ \sigma_{\hat{x}} \text{ variance of the third estimate} \]

(3)

\[ \hat{x}_3 = 18.13 \text{ kn.} \]
\[ \sigma_{\hat{x}} = \sigma_{\hat{x}_3} = 0.019 \]
\[ \hat{x}_4 = 18.7 \text{ kn.} \]
\[ \sigma_{\hat{x}} = \sigma_{\hat{x}_4} = 0.05 \]
(a)

\[ \hat{K}_4 = \frac{\hat{\sigma}^2}{\hat{\sigma}_3^2 + \sigma_5^2} \]

\[ \hat{K}_4 = \frac{0.019}{0.27} \]

(b)

\[ \hat{X}_4 = \hat{X}_3 + (\hat{X}_4 - \hat{X}_3) \hat{K}_4 \]

\[ \hat{X}_4 = 18.13 + (18.7 - 18.13) 0.27 \]

\[ \hat{X}_4 = 18.28 \text{ kn. (fourth estimate)} \]

(c)

\[ \hat{\sigma}_4^2 = \hat{K}_4 \sigma^2 \]

\[ \hat{\sigma}_4 = 0.27 \times 0.05 = 0.013 \]

\[ \hat{\sigma}_4 \] - variance of the fourth estimate

(4)

\[ \hat{X}_4 = 18.28 \text{ kn.} \]

\[ \hat{\sigma}_4 = \text{var} \hat{X}_4 = 0.013 \]

\[ X_5 = 18.9 \text{ kn.} \]

\[ \sigma_5^2 = \text{var} X_5 = 0.05 \]

(a)

\[ \hat{K}_5 = \frac{\hat{\sigma}^2}{\hat{\sigma}_4^2 + \sigma_5^2} \]

\[ \hat{K}_5 = \frac{0.019}{0.27} \]

\[ \hat{K}_5 = 0.20 \]
(b)

\[\hat{x}_5 = \hat{x}_4 + (x_5 - \hat{x}_4)k_5\]

\[x_5 = 18.28 + (18.9 - 18.28)0.20\]

\[x_5 = 18.40 \text{ kn. (fifth estimate)}\]

(c)

\[\frac{\hat{\sigma}_5}{\sigma_5} = k_5 \text{var} x_5\]

\[\frac{\hat{\sigma}_5}{\sigma_5} = 0.20 \times 0.05 = 0.01\]

\[\frac{\hat{\sigma}_5}{\sigma_5} - \text{variance of the fifth estimate}\]

\[x_5 = 18.40 \text{ kn.} \quad \sigma_5 = \text{var} x_5 = 0.01\]

\[x_6 = 17.7 \text{ kn.} \quad \sigma_5 = \text{var} x_5 = 0.05\]

(a)

\[k_6 = \frac{\hat{\sigma}_5}{\sigma_5 + \sigma_5^b}\]

\[k_6 = \frac{0.001}{0.0051} = 0.16\]

\[k_5 = \frac{0.0051}{0.0051}\]

(b)

\[\hat{x}_6 = \hat{x}_5 + (x_6 - \hat{x}_5)k_6\]

\[x_6 = 18.40 + (17.7 - 18.40)0.16 \text{ kn.}\]

\[\hat{x}_6 = 18.28 \text{ kn. (sixth estimate)}\]
This example shows a decrease of the weighting factors' and variances' magnitudes, therefore maximum probability for the improved estimates to be the true values of the measurements. The most probable velocity should be 18.2 kn in this example. (see fig. 14)

When the previous numerical example is further calculated, it would show that $\hat{K}$ approaches zero after some time. (see fig. 15)

From fig. 13 (page 47), it can be seen that the measurement $X$ is completely separated from the prediction and the optimal estimation loop. The optimal $\hat{\theta}_n$ estimate will stay the same regardless what happens at the measurement connection with $X$.

In simple words, if $X$ does not obey the requirements that it has a constant value, then the estimate $\hat{\theta}_n$ (after $\hat{K}$ has become zero) stays at its once indicated value. This feature clearly explains the weak side of a Kalman Filter and shows that the exact model of $X$ should be known.

This also explains that the Tracking-Filter in an ARPA never will be the form of a Kalman Filter. Such a tracker would after acquisition and prolonged tracking of a target in steady course and speed conditions (also from own ship) always predict for steady conditions, even when the target and/or own ship would alter course and/or speed.
Fig. 14  Variation measurements v improved estimates
Fig. 15 Variation of $K$ with respect to time
Fig. 16 Decrease of the variance
The former described disadvantage of the Kalman Filter explains the use of $\omega - \beta$ filters in advanced navigational equipment such as ARPA and "self tuning" autopilots (e.g.: Kockum Sonic's fully adaptive autopilot Steermaster 2000) (See fig. 17)
5.3. $\alpha-\beta$ FILTERS BASIC PRINCIPLE

Fig. 18
The filter has "gains" $\alpha$ and $\frac{\beta}{T}$ where $T$ is the sampling period.

In a radar for example, $T = 3$ seconds whereas $\alpha$ and $\beta$ in most cases are chosen so as to obey the relationship:

$$\beta = \frac{\alpha^2}{2-\alpha}$$

This equation is a control theory necessity and has to be fulfilled.

For instance: $\alpha = 0.50$ and $\beta = 0.17$

In the case of an ARPA filter, $\hat{X}_{n-1} + T\hat{X}_{n-1}$ is the predicted position, $\hat{X}_n$ the estimated velocity and $X_n$ the estimated position of the target.

If the previous mentioned values for $\alpha$ and $\beta$ are used in an ARPA filter, then the response to a ramplike position change will be tracked and predicted with a settling time of 50 seconds and an overshoot of about 30% (scanner revolution period $T = 3$ seconds.) (see fig. 19)
**CHAPTER SIX**

**APPLICATION OF A KALMAN FILTER IN AN INTEGRATED NAVIGATION**

The 2 systems dealt with as "Integrated Complementary System" and "One Dimensional Kalman Filter" are both limited by some disadvantages in practice.

As a matter of fact, the "Complementary Integrated Navigation System" only once is able to compute the filter gain. This means that with the already available variances of the different errors, the optimum filter gain has already to be derived at the beginning of the process and this constant gain is used for the calculation of next estimates and their variances.

There is no recursive process which would further decrease the magnitude of the weighting factor or filter gain which in turn would affect the quality or accuracy of the next measurements.

As far as the "One Dimensional Kalman Filter" is concerned, one channel is available for the measurements of a constant quantity.

The disadvantage within this system (which has been explained in chapter 5) is the fact that the filter is not able to cope with deviations of X from its assumed model which might occur during the measurements. (e.g: change of speed or course during a manoeuvre). A One State Kalman Filter only can perform for a constant X.
The integration of a Kalman Filter within a "Complementary Integrated System" can combine the advantages of both systems and minimize or eliminate their disadvantages at the same time.

6.1. INTEGRATED SYSTEM WITH OPTIMAL KALMAN FILTER
(EXAMPLE 1)

Fig. 20 Realisation of an "Integrated System" with "Optimal Kalman Filter"
The salient features of such a configuration is the possibility to acquire data from 2 independent sources in order to measure the same quantity or variable.

In addition, errors' behaviour within the 2 systems should not be correlated. Moreover, the built-in Kalman recursive algorithm will provide for the automatic generation of, not only weighting factors $K$, but also minimum variance of each computed best estimate.

6.2. INTEGRATED SYSTEM WITH OPTIMAL KALMAN FILTER (EXAMPLE 2)

The realization of the system on page 65 (fig 20) can be changed into the next diagram (page 67 fig. 21) for the case that $S_1$ is a "random step". In addition, $S_2$ should be independent of $S_1$ and the variances of $S_1$ and $S_2$ should be known.

The process implies previous statistical knowledge of the errors' behaviour within both systems. In addition, there is need to acquire information on the fact that $S_1$ should be a constant random error.

The integration of a One State Kalman Filter will act as an estimator for $S_1$. As a result, only a minor estimation error will stay after elimination of the disturbances.

The tremendous advantage of such a system is that the Kalman Filter works independent of the model of $X$. 

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This principle may surely be applied in the future integration of G.P.S. and LORAN C in Europe and this may also be the reason why LORAN C will not be phased out in Europe and even may be expanded over large areas of the World despite full operation of G.P.S. in the near future.

**Fig. 21** Integrated System with "Optimal Kalman Filter"  
(source: latest articles)
If we presume in fig. 21 (page 67) that the system 1 is Loran C with an unknown constant position error S1 (random step), system 2 represents the G.P.S with random position noise S2.

Fig. 22 (a) and (b)
Now by taking the difference Measured X1 - Measured X2, one obtains S1 - S2 as input for the One-State Kalman Filter. (see fig. 23)

![Fig. 23](image)

The output of this Kalman Filter will be the estimate S for the random step S1 and the S2 noise will be completely eliminated. (see fig. 24)

![Fig. 24](image)
After this, the estimate for the position \((X)\) is obtained by taking:

\[
\hat{X} = X_1 - S \\
\hat{X} = X + S_1 - S
\]

and because

\[S_1 = \hat{S}\]

\[\hat{X} = X,\] which is a practical errorless position. As it has been demonstrated here and mentioned previously, the complete error processing part is not affected in any way by the model of \(X\) anymore.
7. INTRODUCTION

The successful application of huge advances made in microprocessor, sensor, data transmission, information display and control technology in the maritime field has brought about a very new concept of navigation which has very dynamically evolved from "state-of-art" to precise science, and which nowadays is becoming "microprocessor-based automated navigation".

The expression "microprocessor-based automated navigation" may be very ambiguous. Therefore its misinterpretation may lead to understand it as "navigation and decision-making process" solely based upon microprocessors together with the extensive use of automation. In this context however, it refers to maximum performance of routine and tedious tasks in navigation, engine control and monitoring, default detection etc. by means of sophisticated electronics and automated processes and/or operations, whereas the ultimate decision, although supported by high technology is left to the officer of the watch.

"Microprocessor-based automated or semi-automated navigation" starts where the conventional manning of ships ends,
and this evolution has totally generated extremely significant changes which presently are affecting the whole international maritime community.

The key words behind the whole process are referred to as automation and integration, which have reached so sophisticated aspects thanks to the high technological progress achieved in the field of what is referred to as the "third revolution". (Microprocessors, digital computing, better information engineering, etc.)

But automation and integration have directly been "prompted" by the sake of reducing manning levels as far as the machine would safely and efficiently replace the human operator in his performance of specific tasks within his daily work on board vessels. Therefore, the use of automation and integration on board modern vessels is twofold i.e.:

1. economical reasons which have been generated by extremely severe competition partly explained by the Developing Countries’ breakthrough into the shipping market, as well as high crew expenditures which are so different between the Developed and Developing World...

This has led to the reduction of crew numbers on board modern vessels for better savings. And this also has brought Thomas C. Gillmer and Bruce Johnson (10) to argue that "the reduction of crew size is an assurance of continued economic vitality; this factor alone, which reflects the increase of overbearing operating costs of a naval fleet, must be a primary consideration for the continuance of a merchant fleet."
Their arguments are supported by B.S. Makhija (11) who puts forward that "although the application of work study methods and reorganisation of shipboard tasks have yielded crew reductions of the order of 25%, for higher savings in the region of 50% or more, ships must be specially designed with minimum manning in view."

2. reduction of the seafarer's workload in a complicated/ hostile environment.

Each of these 2 aspects will in turn affect the effectiveness and efficiency of ships' operation, whereas safety of navigation during coastal passages and approaches to ports would greatly depend upon accuracy of navigation.

But accurate navigation on board modern vessels lies upon the quality and quantity of equipment and the level of their integration on a bridge which is the "ship operation center," thoroughly designed and developed for operating a ship at peak efficiency.

7.1. BRIDGE AUTOMATION

The automatic measurement, processing and integration of all the navigational and other available data for the steering and monitoring of ship's different stages performed from the bridge is referred to as bridge automation.

In bridge automation there are several functions or tasks to be considered of which the most important are:
7.1.1 AUTOPILOTAGE

The awareness of the fact that manual steering in course and track keeping is not only costly but also "less effective than desired" (10) has prompted the design of autopilots which work according to a closed loop with a pre-planned programme held by an internal controller continuously comparing its prescribed input (desired course/track) to the ship's actual course/track, and using any discrepancy between them for generating a rudder deflection which minimizes the discrepancy in an economic and safe manner.

But the various problems arising from poor steering control (i.e. poor stabilization on a prescribed course) has justified the incorporation of adaptive steering control systems currently referred to as adaptive autopilots. Their principle is based upon optimal control laws.

The adaptive module is able to adjust the control parameters of the autopilot for the best course keeping, depending on weather conditions and yaw, by entering its own instructions to the autopilot as has been preset by the navigator.

These new developments were introduced due to the fact that navigation in narrow waters required a higher level of accuracy in course and/or track keeping whereas open sea routes should be optimised and this again implies, not only a steering control system able to cope with the ever changing ship's parameters and sea and/or weather conditions, but also an accurate position fixing module and a
gyrocompass from which appropriate information is extracted in order to feed them back to the control unit.

There is a continuous interface between the position fixing module, gyrocompass and controller in order to get the ship at the right track (or pre-planned track) and at the right moment. There will probably be the integration of the Global Positioning System (G.P.S.) with the best available earth based system for position fixing in order to optimise course and track keeping for modern ships.

The features of such an adaptive autopilot is to precisely and economically guide a ship on a preselected course and/or track ensuring minimum use of rudder and therefore drag reduction. The rudder orders being so optimised help decrease fuel oil consumption. (More orders when necessary and less when not). As regards, the greater accuracy of course and/or track keeping on ocean passages particularly when great-circle navigation has been optimised would reduce steaming time and therefore fuel consumption.

However, a lot of simulator instructors who provide various advanced courses for pilots, masters and chief mates still claim of very low exploitation of autopilots by the trainees especially when a rate of turn indicator is available. As a matter of fact, they have noticed the low use of the instrument during certain manoeuvres which could have been successfully performed with the rate gyro indications.

The example of the ferries navigating between Sweden and Finland is put forward to emphasize the feasibility of such manoeuvres using a rate of turn indicator.
Kockum Steermaster has possibility to follow automatically a prescribed turn.

The advent of the autopilot has greatly contributed to more precise navigation and greatly reduced the human workload especially in open seas. Experience has shown that in certain specific conditions, its performance is by far much better than the helmsman's.

7.1.2. ARPA

The determination and assessment of collision risks by means of radar has replaced the traditional approach for collision avoidance since the Second World War...

Unfortunately, the advent of the radar in navigation did not significantly decrease the rate of casualties which resulted from collisions. Ironically, some accidents have been called "radar assisted collisions" because of misinterpretation of radar vectors or even overcomplacency onboard the two vessels involved in the casualty.

From manual and/or "mental" plotting of targets which is time consuming as well as subject to serious errors of appreciation, the determination and assessment of risk of collisions has been automated by fitting a microprocessor to a radar set. This development makes it possible to automatically acquire a certain number of targets, determine and assess risk of collision, formulate a trial manoeuvre and monitor it in a relatively short time.
An Automatic Radar Plotting Aid (ARPA) represents the above described equipment and since its inception on the bridge, a great load has been obviated from the navigator who benefits from ARPA warnings whenever a target is on a dangerous track with respect to "it".

The possibilities offered by such an equipment are considerable compared to a radar performance and the raster screen enables the use of ARPA even in daylight.

Also, ARPA in modern navigation is more and more becoming navigational "anti-grounding" instrument. As regards, it is worthpointing the benefit of having an ARPA equipment for narrow waters navigation with the possibility of setting a pre-planned track by means of electronic navlines which are the correspondent of parallel indexing on radar screens.

But as has been earlier mentioned (Chapter 3) the innovation in modern navigation is the integration of ARPA with the electronic seachart. This interface, although not exhausted yet because of electronic charting which is, in fact at its early stage, will represent an invaluable tool for the navigator during the forthcoming years. As a matter of fact, maximum advantage can be derived of a position fixing system, "anti-grounding" device and "anti-collision" equipment from the same display.

However, imprudent use of ARPA has been the cause of a few serious collisions. As regards, it is worthrecalling the tragic collision between the steamship Admiral Nakhimov and Bulk-carrier Petr Vasev which brought A. Yakushenkov to state that "the lack of action until when it was too late can be explained by wrong interpretation of situations
Another integration of ARPA with a direction finder has been envisaged by 2 navaid manufactures in West Europe with the possibility to detect, by means of an electronic beam a ship transmitting V.H.F. (Very High Frequency) signals. An ambiguous problem would be solved especially for the identification of communicating sources. Here also, maximum advantage would be derived from such an equipment if all ships were fitted with the same system.

7.1.3. VISUAL BEARINGS

There are more and more evidences that the determination of position by means of visual bearings would less and less be utilised in modern navigation. This is partly explained by the location of azimuth mirrors outside of the bridge which is no more a good incentive for external bearings.

In the future, the ceiling of the modern bridge will be equipped with a periscope azimuth mirror which will be at the One-Man's-Bridge level. From his seated position, he will be able to take visual bearings with this type of equipment. The possibility of cross-checking them with other navigational information provided to him on a centralised display will represent another step towards safety. This new arrangement exists on the "Full Mission Ship-handling Simulator "SUSAN" (Department Of Nautical Studies Hamburg, FRG.) and its use is quite easy and practical.
7.1.4. AUTOMATED ASTRONOMICAL NAVIGATION FOR FUTURE OFFICERS

There are a lot of values attributable to astronomical navigation. Unfortunately, the advent of powerful means for position fixing has progressively reduced the use of the traditional sextant, astronomical almanacs, etc. on modern vessels. The "remarkable loss of interest of this method extensively used for position fixing in the past is not only due to the limitations in the measuring equipment, but also because of the laborious computations involved which have changed little with respect to classical ones of the first half of the century." There are also some difficulties attributable "to overcast skies as well as shortness of observation periods". (13)

In order to overcome the above mentioned problems which have created the relegation of astronomical navigation to least order means for positioning, the sextant has been greatly improved by fitting it with an additional equipment consisting of:

1. a night viewer which replaces the usual telescope to allow observation of the horizon in darkness.
2. an automatic reading of altitude made practicable by a ten-bit encoder mounted on the index arm.

But the innovation introduced by this equipment is the fact it has been developed so as to be part of an integrated navigation system. As a matter of fact, the automation of the system has enabled an automatic reading of celestial bodies’ altitude. "The measurement obtained is dir-
ectly transmitted to a personal computer and then a set of computer routines written in a package called the Astronomical Navigation Package (ANP) proceeds to:

1. compute ephemerides
2. correct altitude
3. compute the fix position using n observations and least squares techniques." (13)

The Celestial Navigation Automated System (CNAGS), developed by V. Nasro, A. Russo, R. Santa Maria, A. Sposito and M. Vultaggio (13) represents a modern concept of astronomical navigation which can take maximum advantage from "a completely free and cheap reference system continuously available." Moreover, it can relieve the future officer of the watch from boredom of long control and monitoring of navigational data, engine performance parameters etc.

However, there is a "gap" between this equipment and its integration in a "total ship-system". As a matter of fact, the "CNAGS" has not found much support from the maritime community and, there are lots of evidences showing that the equipment will not be part of "fully integrated-automated modern ships." One of the main reasons for that is the investment to carry out in order to enable its "interface" with other navigational equipment.
7.1.5. PLOTTING TABLES

Plotters’ emergence in modern navigation represents a further step towards reducing the human workload on the bridge. Plotters give the actual print out of ship’s motion based upon navaids’ information.

In the future however, this equipment which uses a set of permanent ball pens (for ordinary paper with X,Y co-ordinates) or normal pens (for navigational charts) will be replaced by more sophisticated devices referred to as electronic chart tables. This equipment can represent the output of integrated navigation systems and automation on the modern bridge.

Unlike a normal plotter, it provides the actual motion of the ship as a clear spot of light projected from the bottom of the electronic chart table upwards on a real navigation chart.

However, one should be extremely careful when using this type of advanced equipment. There is and will always be a certain "fetishism" about navaid indications and whether they are right or wrong, they are then considered as reliable and therefore with confidence.

As regards this specific feeling inherent to most of the seafarers, Rear Admiral R.O.Morris (5) explains that he has been "reliably informed that Merchant Naval Officers display the same faith in modern technology." He carries on adding that he is in knowledge of "cases where, when the position given by the machine and the evidence of
radar, echo-sounder and eye-ball Mark I disagreed, the machine was believed despite all the evidence to the contrary." He then concludes that "the simpler black boxes always appear to give the correct answer."

This is also stressed by J.H. Mulders (*) who observes that "many maritime disasters have their roots in misjudgement of the capabilities of advanced technology in modern systems and methods and in many cases the simultaneous neglect or rejection of good information from less advanced but at that moment more reliable systems."

The fact that navigators would be exempted from manual plotting of ship's positions on a chart may simply eliminate the possibility of checking, whether the position given on the electronic chart table is in conformity with external evidences acquired by themselves (e.g.: visual bearings) and good seamanship.

The quality (accuracy) of the electronic chart information will chiefly depend upon the accuracy in the measurement of ship's different parameters (i.e.: speed, heading, etc.) and the accuracy of position fixing systems of which the integration will provided the ship's position on the chart.
7.1.6. ENGINE CONTROL

Automation nowadays has enabled the automatic control of the engine room from the bridge and this aspect of "bridge-engine-remote" control system definitely will be applied on board modern vessels.

In a conventionally manned engine room, manoeuvring orders given from the bridge by a telegraph were practically executed by the engineer of the watch in the engine room. Obviously, the transmission and response process could be dangerously delayed according to the type of engine and this factor could put a ship at risk.

Casualty investigations have proven the extreme importance of time factor especially in crash manoeuvres for collision avoidance and direct control of the main propulsion from the bridge will greatly benefit the user in critical situations.

Developments in control automation and remote control have tremendously speeded up the process and "relieved the engineer of some repetitive arduous tasks and in many cases, have improved the general operation procedure within the engine room." (14)

With these developments, engine rooms on board modern vessels are unattended due to the fact that the main propulsion is remotely operated from the "ship's operation center". The whole system is backed up by high degree of automation with advanced control and monitoring equipment providing centralised information display. In addition,
various alarm systems with sensors detect failures and/or faults and provide warnings to the bridge.

Operating the engine from the bridge is a decisive step towards the integration of deck and engine departments. This way of operating the engine room is much more efficient than the traditional one which, very often created "conflicts" between bridge operators and engineers.

Unmanned Machinery Spaces (U.M.S.) will become more and more popular during the future. Therefore the only alternative left to the former engineer would be the acquisition of either ashore jobs or eventually a reconversion into a dual purpose or bivalent officer.

7.1.7. STABILITY AND HULL CONTROL

A lot of developments have been introduced in ship's stability calculations and hull control during the last decade. From Ralston indicators, stability calculation methods have gone through loading calculators, micro-computers and, very recently micro-computers with sensor inputs.

The process of stability calculations, which was time consuming, tedious and very complex (due to the fact that the location of the cargo had to be carefully measured and recorded, together with its weight) has been tremendously speeded up by the new techniques.

The assumption under which the already calculated dynamic stability by the naval architects using the ship's particulars and sample loading conditions represents the
best assessment of the ship's stability data are not valid anymore. This fact underlines the criticism with which advanced methods of ship's stability calculations on board modern vessels do not consider the static stability provided by the shipyard as a safe guarantee of the ship's dynamic stability. In other words, the calculated static stability, even though complying with the regulations should not exempt the personnel on board to determine the dynamic stability using available modern techniques.

As a matter of fact, the relevant loading data for the case of micro-computer stability calculations are acquired by an operator, and keyed to a micro-processor (with specific software for a particular ship) which computes all the stability parameters ranging from deadweight to metacentric height.

The same data for stability calculations using micro-computers with sensor input are directly acquired from the ship's sensors and automatically given to the "ship's operation center" by means of advanced remote data transmission. Those data are automatically processed by a computer which extracts the relevant information (static and dynamic stability, static and dynamic stress) which is finally presented to the operator.

The remote transfer of digital data, an extremely advanced way of dealing with information reduces the workload from the operator who will never have to perform lengthy and complex stability calculations from which hull performance is also derived.

In both cases, quality information related to bending moments and shear forces are provided to the operator
on a visual display unit (V.D.U). However, the first method is different from the second in that the former might be subject to erroneous keying of data input by the operator, whereas the latter is based upon sensors readouts, data handling and computing techniques of a large network of data acquisition, transmission and presentation without operators' interference in the process. Moreover, it obviates errors and therefore is more reliable than the first method.

Despite their availability on board modern vessels and the great benefit that can be derived from them, G.F.Hudson, R.A.Johnson and D.P.Lawrence (14) argue that the modern stability indicators are powerful tools which "furnish the seafarer with dynamic stability information" but which in their belief, are still not utilised to their full capacity.

7.1.7.1. "RESONANCE AVOIDANCE" CONTROL

In modern navigation, the safety of the ship is not any more left at the mercy of events such as predictable bad sea and weather conditions.

As has been sadly shown by experience, Mathieu resonance has been found to be the cause of casualties which resulted in very severe damages, total losses or even capsize. As regards, the loss of the German barge carrier Munchen in North Atlantic in December 1978 is a case in point. Despite the fact that, up to now the investigation into this special case yet has not provided the maritime community with a concrete and tangible evidence about the
real facts pertaining to this sad event, resonance is believed to be one of its causes.

Therefore, with the potential knowledge of wave patterns (acquired from practical experience, towing tanks experimental models and computer tests) and their negative and/or dangerous influence on ship safety, softwares for the determination of resonance have been developed to help masters take the right decision (change of course, speed or both) whenever an encountered period of roll is within the unsafe limits i.e. when:

- $T_E$ close to $T_Φ$

where:

$T_E$ - encounter period of waves

$T_Φ$ - natural roll period of ship

The data are acquired from electronic inclinometers of which the output is transmitted to a computer for processing. The results are then compared to the ship's natural period of roll according to the specific loading conditions of the voyage. An alarm is given in order to carry out the appropriate manoeuvre when the above mentioned conditions are met.

The generation of warning alarms after automatic determination of imminent resonance by means of roll sensors and micro-processors will obviate the need for the operator to refer to diagrams for determining the encounter period of roll.
7.1.8. CARGO DATA MONITORING

The data acquired from cargo spaces are automatically transferred to a specially dedicated area within the "ship's operation center", thus enabling continuous monitoring of cargo parameters without endangering the life of a human operator who previously had to directly take samples from cargo spaces. Cargo data are displayed in a simple and concise form and any time, the officer of the watch can easily have access to them.

Alarm systems encompassing advanced sensor technology and data transmission techniques are an integral part of the bridge computerized monitoring system.

7.1.9. NAVTEX

NAVTEX will become part of the Global Maritime Distress And Safety System (G.M.D.S.S) by which navigational, meteorological warnings as well as other relevant and urgent messages related to maritime safety are transmitted.

Although up till now limited by its coverage, the system is widely used for navigational purposes. It represents a real support to navigators who take advantage from its transmissions.

In the field of communication, technological developments have brought about new techniques and equipment. One of them is the Standard C terminal, which will progressively
replace the Standard A. The former may be used "for digital data only at 600 bits/second. The equipment is low powered and operates via an omni-directional antenna" (14) which gives a better performance than communications with the Standard A equipment. One of its features is its low cost compared to the previous one. The "cost-performance" parameter of the Standard C equipment will bear an important character in the near future.

The future implementation of the G.M.D.S.S. will eliminate the function of radio operators (or officers) on board modern ships. There will be a communication center so "flexible" that it can easily be operated by any crew member.

7.1.10. OPTIMAL ROUTEING

The above presentation of the modern bridge with the support of external stations for communication and position fixing have laid down excellent perspectives for optimal routeing where information related to weather and sea conditions are of paramount importance. There will be a bulk of data ranging from meteorological events to warnings and shore-ship communications related to management purposes (or else) which will need proper and efficient handling.
CHAPTER EIGHT

TRAINING IN INTEGRATED NAVIGATION SYSTEMS AND PROCEDURES

INTRODUCTION

Economical conjuncture, high technology applied in the maritime field through automation, as well as better instrumentation and integration on board modern vessels leading to unmanned machinery spaces and, excellent shore-ship satellite based-communication links discarding the function of the radio officer with the future implementation of the G.M.D.S.S. are the main factors which have brought maritime education and training and ship's manning at the cross-road of their history.

The new trend in shipping has defined other subject areas in which the future navigation officer has to possess knowledge and skills which would help him understand the status of systems he will be dealing with.

The term "data handling skills" (14) which has generated "completely new procedures for operating merchant ships" better explains this concept.

In this respect, the interface "ship (as a total system)-officer of the watch", previously based upon tedious routine tasks with enormous input of workload, will soon be definitely shifted to monitoring of centralised display of
information providing the best "tools" for a correct and effective decision.

As mentioned by G.F. Hudson and R.A. Johnson (14), the decision making process itself, together with the presented information on which it is based, and the technology by which the decision is implemented is termed "Decision Support Systems". They carry on pointing that this certainly is a "major area for future ships' officers to have competence."

As far as the management of modern ships, conceived as a total system is concerned, the modern way of operating them will require other managerial skills which have been created by the above mentioned changes.

Modern shipping therefore needs reshaping of a new type of seafarer whose competency will cope with the new trend.

8.1. EDUCATION AND TRAINING

The last two decades have been characterised by the introduction of new techniques for improving accuracy and safety of navigation (e.g.: satellite navigation, filtering techniques, ARPA, etc.) hence efficiency of ship's operation. Recently, there have been very fast developments in the fields of automation, shipboard instrumentation and communication with the same objectives.

However, P.Fjellheim and E.Gjeruldsen (15) observe that because of the fast pace towards modernization, "the education of the navigators lags to the technological develop-
ments." But as one knows, there is a "genuine" link between the education of seafarers, navigational equipment and casualties.

According to Cockroft (16), "there is not much decrease in the percentage of collisions for ships over 10,000 gross registered tons", whereas M.J. Dove, R.S. Burns and J.L. Evison (3) argue about "the opportunity to fit integrated navigation systems, at extra cost to the shipowner, when there can only be a very slight decrease in the probability of casualties."

As for Jens Froese (17), he states that "enough evidence was given that modern equipment also could lead to less effectiveness, less reliability and the need for better and more trained operators."

This argument is strengthened by J.H. Mulders (*) who puts forward that "in modern navigation the human navigator is confronted with systems, aids and methods which dilute his ability to perceive how good or bad an observation is." He then adds that "it could be said that the "gap" between nature and the human navigator is widening."

These statements of value can certainly highlight M.J. Dove R.S. Burns and J.L. Evison (3) on the necessity to put much more emphasis on education and training due to the fact that "there has always been a requirement for navigators to know the exact status of their navigational systems. Also, there is a need for at least a basic understanding of the principles involved in order to predict how any status changes may affect the results." (18)

For the technology is already available and, although it will never provide 100% of safety, its shortcomings up to
a certain level may be offset by proper level of education and training.

8.1.1. INTEGRATED SCHEMES

The integration of the deck and engine departments has generated a crucial effect on the way of manning a modern ship referred to as the "Ship of the Future", the "Intelligent Ship", or the "Rationalised Ship", which also can be expressed to be the "Efficient Ship of the Future."

Whichever the name ascribed to this modern ship is, there is one common concept which underlies her manning i.e.:

- she is especially designed to have a significant reduction in crew number with only one man on duty on the bridge. (One-Man-Bridge)

Analysing the trend generated by total integration with high level of automation, the present step made by some Developed Countries towards One-Man-Bridge watch arrangements can be understood as a normal stage of progress in ships' operation.

But one should bring into attention that this trend has been, first of all dictated by economical reasons. As regards, the arguments put forward by David Mitchel (19) is quite significant. He points out that the only alternative for U.K. shipping to survive is to take "maximum advantage of education and training facilities of the country, so as to provide crews which can operate ships more efficiently and with lower number than their competitors
from the Third World and elsewhere."

The new trend involved (and still involves) a big capital investment to carry out various studies and tests on integrated-bridge-simulators (e.g. Schiffsführungs-Und Simulationsanlage-SUSAN), or even real trials at sea performed by Norway in order to examine a One-Man-Bridge and measure his performance under different working conditions.

These studies have highlighted several aspects of the interface One-Man-Bridge-"Modern Engine Room as well as workload assessment and new human attitudes on the "Bridge of the Future".

According to study results, a One-Man-Bridge concept is realisable when the officer of the watch is backed up by advanced and reliable technology. But as regards that high technology, G.M. Veenman and J.H. Mulders (20) observe that "much more of it is safety-critical and needs studies and tests before its high reliability is proved."

8.1.2. MARITIME EDUCATION AND TRAINING INSTITUTIONS

The "Ship of the Future" has been designed to be operated by only one man from the bridge. Obviously, the education and training of such a person should be different from the conventional way of educating and training within 2 segregated departments.
In the Netherlands for instance, S.J.Cross (21) explains that "the training institutes and nautical colleges are advised (by shipowners) to adapt training programmes to the new requirements and come up with a new and more efficient product." The "product" so defined is a polyvalent or dual-purpose officer.

As for the Federal Republic of Germany, Jens Froese (17) notifies that "with the term 1989/1990, beginning in September 1989 (starting in September 1989), the Hamburg School of Nautical Studies will introduce a new training programme for ship operation officers who will be licensed for deck and engine department.

If one considers that the French maritime education and training schemes already are based upon this type of education, while the Swedish and Danish systems have been recently changed to dual licensing and finally, if one recalls David Mitchel's arguments as to modern maritime education and training, one ends up with the general picture of the new trend in the maritime educational systems of the most developed countries in West Europe.

What has to be considered in this respect is the fact that all these countries are aiming at producing the most competent "product" for operating ships at peak efficiency.

But as D.M.Waters mentions (23), "maritime education and training should first of all cover the needs of the marine department and/or shipowners." Therefore, their maritime education and training instutions have the responsibility to shape the profile of such a man.

But as far as that profile is concerned, G.M.Veenman and
J.H. Mulders (20) state that "the blueprint of the new navigator will show:

- less importance of traditional shiphandling capacities,

- natural aptitude and skill in operating automated systems,

- detailed technical knowledge changing into an overall insight in technological and physical processes,

- a different but important place for human factors and man/machine relations..."

They conclude mentioning that the new navigation officer will be a "process controller and operations manager in a teamwork environment."

Obviously, the selection of the future officer as presented above, who will be involved in single watch arrangements should be based upon totally different criteria up to now used in maritime education and training institutions.

Some experts even argue that it should be as severe as the selection of airline pilots because of increased responsibility and therefore greater "psychological pressure."

This has led J.H. Mulders (*) to stress that greater emphasis should be put not only on the physical aptitude, but also on psychological tests of the trainee.

The training itself, most of all based upon shiphandling simulations should encompass "complex situations" (*) in
order to get the trainee familiarised with critical and tricky events in which the time factor, termed in seconds will bear an invaluable character.

The simulation training should aim at improving the trainee's attitude because of the tremendous influence it has on performance.

In this respect, the requirements should be clearly defined by the simulator instructor in charge of the training. Moreover, he should be very critical in assessing his trainee's performance. For, what goes right here may go wrong there and vice versa due to the difference between the "simulator-cubical and sea environment."

The proper assessment of trainees represents a difficult field in which simulator instructors have to make maximum use of their experience combined with psychology. The latter should be improved.

It is necessary to combine efforts in education and training in particular due to the fact that "the industry needs eligible human operators to control the navigation process in a "maximum safety-minimum economic loss" strategy."(20)

There is much more to say about the profile of the future navigator, his knowledge, skills and capabilities as well as the level of his education and training.

Bearing that in mind, one draws attention on the paper presented by G.M.Veenman and J.H.Mulders (20) at the International Navigation Congress of the International Association of Institutes Of Navigation (23).
The authors not only describe "their views on future training requirements for navigators with respect to the influence of new technologies in the sea-and air transportation systems, but also give an outline of the new work-environment as a natural consequence of hi-tech implementation and describe a new philosophy towards recruitment, selection and training of this new navigator."

The curricula governing the bivalent schemes vary from country to country in West Europe but the final objectives are identical. There are many values attributable to this specific maritime educational system i.e:

- the dual-purpose education scheme is the only type of education by which the bridge officer is able to understand a ship as a whole or total system,

- it provides flexibility to the trainee and appropriate basic knowledge, especially in applied science and computer based-systems,

- builds awareness of potential and limits of micro-chip applications and knowledge based systems,

- improves team work in the case when the engine is monitored from the bridge by another polyvalent officer,

- enables quick familiarization with complex systems more and more present in the daily life of human beings...

As for the Developed Countries (in concert with their maritime and training institutions) which have prompted another concept of deck officers' education and training,
the bivalent scheme is a challenge which should be successfully coped with. But this also will require an excellent co-operation of all the parties involved in the project.

8.2. TRAINING IN INTEGRATED NAVIGATION SYSTEMS

Data processing principles within integrated navigation systems are generally very complex procedures involving a combination of knowledge in various technical disciplines such as physics, mathematics, electronics, electrotechnics, control theory, etc.

This has brought B. Berking (24) to assess that electronics, computers and automation, because of their increasing importance are topics which have an enormous impact on navigational education and training...

He carries on mentioning that the "production of information will be replaced by the extraction of relevant data from complex information systems and particularly by judging the quality of information." He concludes stressing that "this require the mariner's understanding of principles of electronics and data processing, particularly the potential and limits of computer programmes."

What is reflected from the author's argument is an endeavour to raise the future navigation officer to a level which copes with navigation in its new/modern concept. But this level requires knowledge, ability and skills by far superior to the skilled operator's capabilities.
This is the reason why D.M. Waters (23) points that the consequence of high technology's applied application in the maritime field will "trigger" "a greater emphasis on the need for higher level of education and training..."

What has to be mentioned is the fact that integrated systems are technical as far as their programming is concerned. Therefore, the trainee is not much interested in this part of integrated navigation systems due to the fact they are dealt with by the navaid manufactures.

However, the trainee is bound to understand basic principles and concepts which govern the system. And this fully converges with education and training objectives.

To know basic principles and concepts means to acquire the necessary "tools" for understanding systems' advantages and disadvantages. In other words, from these factors, potentials and limits of navaids equipment and/or instruments are brought to the trainee's knowledge who will have to optimize the use of those aids.

Nowadays, particular attention should be drawn on $\alpha-\beta$ filters in ARPA.

The term "ARPA-assisted collision", which sounds very ironic is in fact, in its deep meaning tragically expressing the limitations of ARPA equipment with manoeuvring ships, as well as the incapacity of many navigators to understanding the behaviour of certain targets on ARPA screen. As a result, collisions in which no action was taken in order to avoid the desaster have occured.
The investigation carried out by the Marine Research Institute of Leningrad into the collision between the Admiral Nakhimov and Petr Vasev has revealed the involvement of ARPA equipment in this casualty. Moreover, it has stressed the necessity for I.M.O. to "specify the ARPA parameters for the case of manoeuvring ships" (25) within Resolution A.422 (XI). For ARPA performance standards for ships sailing on a steady course and constant speed have been already dealt with by the same Resolution.

But this specification will be very difficult to achieve due to the fact that ARPA principle is based upon predictions which are not reliable in manoeuvring conditions and this fact should be known by all navigators.

As a matter of fact, there is a time gap between the moment when a manoeuvre is started (drastic manoeuvre) and the time when the ARPA "realises" the changes and adjusts its predictions and estimates. This time is approximately equal to 1 (one) minute. The situation gets worse in the case of smoother and/or significant subsequent change in courses and speeds of own ship and targets.

The filter would no more be able to handle those situations for a longer period of time which depends on the pattern of performed manoeuvre. (e.g.: a ship on zig-zag course)

The trainee should endlessly be repeated that \( \alpha-\beta \) filters perform correct estimates as long as own ship and targets stay in steady course with a steady speed. And this sentence can be shortened as follows: "correct estimates if only course and speed steady".

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(For better understanding of this principle, refer to Chapter 5, paragraph 5.3.)

In the written examination on ARPA, the trainee should be asked to assess the shortcomings of the equipment and the shortest correct answer should read as given above.

Last but not the least, the tragedy between the Admiral Nakhimov and Petr Vasev and other notorious collisions should always be analysed to the trainees in order to weaken the feeling of overestimation of ARPA capabilities. The awareness of its limitations may play a crucial role in assessing risk of collisions.

As for the Kalman Filter, the problem of filter gains have to be mentioned for they are very seldom properly tuned on board vessels. In addition, its status (advantages, disadvantages) have to be known by the trainee.

8.3. TRAINING IN INTEGRATED NAVIGATION PROCEDURES AND BRIDGE AUTOMATION

A Training in integrated navigation procedures does not necessarily mean training in One-Man-Bridge procedures which concept is presently not envisaged in West Africa, due to the fact it is not presently a relevant criterion for competition according to shipowners.

However, such a training is meant to build skills in the practical use of navigational equipment (e.g.: the practical use of ARPA or rate of turn indicator etc.) as well as abilities to perform well as bridge team according to
the principles of passage planning which bears an extremely important character in modern navigation.

The appraisal, planning of navigation, execution and evaluation which represent the elements of the complex field of passage planning can be properly performed using simulator facilities. Therefore, they should efficiently be utilised for training purposes in passage planning. Their potentials lie upon the fact that specific sea and/or weather conditions, dangerous approaches, critical situations etc., can be simulated using different types of ships.

Many accidents have occurred because of improper and poor passage planning. This is the reason why Y. Draaisma (25) stresses the necessity to put more emphasis on the subject. For up to now, "not much has been done in order to improve safety of navigation from the viewpoint of passage planning", although it is a legal obligation. (I.M.O. Resolution A.285 (VIII))

Therefore, the only remedy to prevent certain types of casualties at sea is to "plan and control navigation instead of sailing ships." (25) This goal could be achieved by means of extensive simulator training on integrated bridge procedures. In this respect, Y. Draaisma observes that the training should mainly be directed towards the improvement of the student's behaviour. He goes on mentioning that it should "be changed in such a way that the desirable professional attitude is achieved as regards watchkeeping and navigation." (25)

Also, simulators can be used to train navigators to react accordingly in emergency situations such as for instance man over board, crash stop manoeuvres, etc., or good nav-
Nowadays, simulators are becoming extensively used for training purposes in maritime education and training institutions and, despite the fact that only a few of them are fitted with "full mission bridge simulators", their utility is undoubtedly not negligible in seafarers' education and training. That is why they represent the best facilities for the above mentioned purposes.

In this respect, training in integrated navigation procedures should be based upon simulator exercises of which the benefits are already known. However, care should be taken in adjusting the training to the systems used in practice. In other words, the training should be rationalised to up-to-date equipment and carried out with depth.

As regards, it is worth pointing the pattern of ARPA training followed by Makarov Engineering School in Leningrad (Soviet Union.) The course is provided during 6 days in which 5 are allocated to 4 hours of watch (normal bridge-watch) everyday, and the 6th day is concluded by a practical examination.

This method enables an involvement of fatigue in simulator training which, up to recently was not designated for that issue in which the human being is known to unwittingly show his real attitude. This should aim at correcting what is adjustable in simulator training i.e.: attitude.

Here also, care should be taken to devise realistic exercises which cope with actual situations encountered by the navigator. Otherwise, simulators may become "dangerous games" which would more worsen than improve attitude.
Several methods should be used to put "pressure" on the trainee and make the simulation exercise as close to reality as possible.

However, it is simulator instructors' responsibility to also stress the limitations of simulator equipment to their trainees by showing, for instance the difficulty of visual assessment of distances in a simulator with outside view. As a matter of fact, targets seem to be more close than they really are...

Having realised what has been mentioned above, one might partly fulfill the objectives of education and training in integrated navigation systems and procedures.
CHAPTER NINE

Discussion

Integrated navigation as stressed in the introduction to this paper has evolved far beyond its original concept and has been the basis for the design and development of fully "integrated-automated bridges" aiming at the operation by one man.

Obviously, such a concept in navigation is extremely dependent upon electronics and computers, this leaving the officer of the watch with a greater responsibility and less workload.

The extensive use of electronics and automation on board modern vessels as asserted by A. Yakushenkov (12) should be understood as a remedy to "strengthen the weakest link in the man-technique-environment system", with the "human shackle" being the "Achilles heel" of the whole system due to certain psycho-physiological limitations, such as insufficient memory and data reception capacity.

However despite his "weakness" the human being is the thinking part of the above described configuration.

A lot of concerns are brought about by this way of operating vessels because of the fact it fundamentally breaks with the traditional method. It also "ignores" some legally binding rules and requirements pertaining to safety of navigation.
First of all, let us consider the education and training aspects of One-Man-Bridge operation which has been already prepared in some Developed Countries' maritime institutions.

A brief analysis of the curricula governing this type of maritime education and training has underlined their common endeavour to produce the most competent polyvalent officer for the optimum operation of ships.

The curricula include applied sciences to navigation with appropriate level of practical simulator and sea training.

But the acquisition of knowledge in as so far as the above mentioned subjects are concerned, and the development of professional skills and good attitudes as regards bridge work, engine control/monitoring and fault diagnosis etc. requires time. There is therefore a fear, that these subjects are only "navigation oriented", this meaning that only the relevant aspects of the concerned subjects to navigation are dealt with. (applied scientific subjects.)

Even though seamanship and the least relevant subjects to modern navigation have been reduced to minimum, one wonders how a polyvalent officer, qualified for deck and engine work could be educated in much shorter period of time than required for the 2 separate branches of education and training? (Deck and Engine departments.)

Some argue that the integration of curricula would significantly reduce the time allocated to overlapping subjects which would be taught in a more concise way.
There is no doubt that this method assures better understanding of a ship as a whole system.

However, how far it would be understood as a total system when there are serious time constraints for "diving" into those subjects and their interconnection in modern navigation?

The answer provided by Captain S.J. Cross (21) for instance will just raise the interest of the debate.

He points out that shortening the educational scheme aims at "a specific training in a very well defined direction, leading to output of very capable officers, fit for the task they have chosen, no more and no less."

It seems therefore that this scheme is aiming at educating and training future navigators for a whole-life career at sea, without much flexibility for reconversion.

As a matter of fact, the scheme as exposed by S.J. Cross is an excellent means for the ab-initio education and training of operators, who represent the best output of maritime education and training institutions in the view point of the most efficient operation of the new generation of ships.

But, what about officers who would like to, or eventually have to acquire another function ashore in the future?

S.J. Cross carries on, concluding that the application of the new educational system is the only way to achieve "the almost impossible goal of replacing two-four-year training periods by just one and half or eventually by just one"
training period."
There is no better statement to point out the time pres­sure for bringing two different programmes of education and training into one.

Despite the "use of more efficient ways of teaching" (21) together with the support of "simulator training for ac­quiring certain skills more quickly" (21), there will be non negligible shortcomings not only due to the implement­ation of a new scheme of education and training, but also caused by ship-operation. This will cause continuous re­adjustment and improvement of programmes in order to reach the required level of education and training.

Is this not the reason why Jens Froese (17) points that as far at the German scheme is concerned, it is only at its experimental stage? But he further mentiones that "one must be convinced that it is qualified enough to replace traditional programmes sooner or later. Otherwise it would mean cheating the participating students" and fooling shipowners.

As a matter of fact, only the Hamburg School of Nautical Studies is undertaking such experiment with only one class.

Because any assessment of the system at this moment would be very subjective. The dual-purpose education programme, in its modern implementation is too young to be properly evaluated.

But a static discussion confined within the educational aspects of One-Man-Bridge operation (although construct­ive) would not carry us any way ahead. The dynamic of our
debate will bring us to consider One-Man and integrated-Bridge operation related to the safety requirements for navigation.

According to I.M.O. Regulations, the bridge at no time shall be left unattended. (International Convention On Standards Of Training, Certification And Watchkeeping For Seafarers, 1978: S.T.C.W. 1978, Regulation II/1, paragraph 4(b)(i).

Therefore, if One-Man-Bridge operation would be implemented on board the modern ship, it would be an evident infringement of some requirements defined by I.M.O., unless the affected regulations would be up-dated in the light of the future trend.

That is why A.Yakushenkov appeals the International Maritime Organization to early examine this question. He says that "more consideration should be given by I.M.O. in anticipating the appearance of "Ships of the future." (12)

Unfortunately, it is a known fact that a One-Man-Bridge watchkeeping arrangement has been/is presently practised at night on board certain vessels (large and small) involved in deep sea navigation, without the international maritime community’s approval.

But the supporters of this practice may oppose that amending a convention in order to adapt it to a given situation is not a real concern nowadays.

This argument which is quite true and practically feasible will bring us to consider another aspect of the debate related to the attitude of the One-Man-Bridge and his work-
It is true that a legally binding rule or regulation can be subject to amendments. However, one should admit that the nature of human being cannot be changed or even rearranged (for the time being), although the attitude of the navigator can be subject to adjustments which may improve his performance or make it worse...

This brings about the problem of degradation of ego very often observed in hard labour conditions. "(Labour conditions are considered as hard if the number of simultaneously observed objects is 10 to 25 while the share of time for concentrated attention is 0.5 to 0.75, relative to the overall working time."(12)

Those conditions unfortunately are experienced by the officer of the watch. Are they more heavy to a One-Man-Bridge who strives to perform his duty of watchkeeping officer according to the rules set by I.M.O. and good seamanship?

The answer is provided by the comparative studies carried out by the Department Of Nautical Studies in Hamburg, with the ship handling simulator "SUSAN" involving a conventional and One-Man-Bridge operation.

The study has revealed that in certain conditions (e.g.: dense traffic, poor visibility, etc.) there was greater workload on the modern bridge than on conventional one. This means that the main objective of total integration (i.e.: workload reduction) is not fulfilled anymore.

Therefore, it seems that economical reasons brandished by
shipowners in order to motivate the significant crew re-
duction of manning levels (14 to 9 crew members) could
lower the benefits derived from high level of automation,
better instrumentation and integration of navigational in-
formation on board modern vessels.

If one assumes that the watch is kept according to the re-
quirements pertaining to safety, how long the officer of
the watch can sustain such attitude and/or behaviour dur-
ing a whole voyage and under the "psychological pressure"
of the "dead man's alarm"?

Would his good seamanship not be affected by fatigue, iso-
lation and boredom? For these three factors may seriously
corrupt the best attitudes.

Bridge simulators are powerful tools for assessing and
weighting the workload. However, they cannot (for simply
practical reasons) be used for investigating into isolat-
ion and homesickness or the combination of the three fact-
ors mentioned before.

May all these considerations blunt the sharpest technology
when they are met and when the decision maker is affected
and "switched off"?

Or would the workload increase if the so-called advanced
technology would not function properly?

In both cases, safety may be put at risk!

These 2 questions give much more weight to A. Yakushenkov's
(12) arguments which are expressed as follows: "the inter-
connection between technology and maritime safety should
be regarded in the light of human factor". But as far as this factor is concerned, D. Todd (27) goes on pointing that "the human component is too frequently relegated to the background, when it is not simply forgotten altogether."

It is a fact that more concerns are nowadays shown towards the improvement of the man-machine interface and, despite a continuous progress in ergonomics, there still is a lot to do in that specific area due to significant drawbacks that should be identified and discarded.

This has led to design the modern bridge more akin to the aircraft cockpit in order to have better control and monitoring over the ship-environment-system and to improve crews' recreation facilities. However, what is the benefit of "fancy" lounges if they are filled with emptiness? There are lots of evidences which show that social relations on board "Ships of the Future" will not be the best if not the worse.

As far as the bridge itself is concerned, many trainees involved in research projects and even officers on board integrated-automated vessels have complained of poor integration. And this has several reasons.

First of all, the needed information is either "far" from reach, or the centralised displays providing useful data are overloaded.

Beside, navaid manufacturers (due to competition) are much more concerned about esthetics of equipment/instruments than about the quality of information and/or their quick understanding. In other words, equipment design is more
taken into account, hence more taken care of than information design.

As regards, it is worth pointing out the long training needed in order to be proficient in ARPA handling which could have been easier if the number of sets (key-sets) were reduced to minimum and/or the layout was to be standardised.

In this respect, it seems (although it may not absolutely be true) that only ARPA simulator instructors can derive maximum benefits from the ARPA.

Another deficiency is the obstruction of the One-Man's-Bridge view by monitors which are located on his horizon line. Moreover, he cannot, from his seating position located at the right wing of the "ship's operation center", properly monitor the "sector from which most of collisions at sea occur."(16)

But, what about the reliability of equipment/instruments which represents the sine qua non condition for the implementation of a One-Man-Bridge control and monitoring watchkeeping arrangement?

This aspect of navigational equipment should be granted due importance in modern shipping because, there will always be a probability of failure. This argument is stressed by B.Berking (24) in these terms: "the application and limits of electronics in navigation are to a high degree determined by safety aspects and the risk of failure." He goes on quoting that: "Whatever CAN GO WRONG WILL GO WRONG." (Murphy's Law) and "COMPUTERS ARE UNRELIABLE-MEN EVEN MORE." (Gibs Law) which "express some attitudes to success and failure."
One characteristic of seafarers is that they accept too easily and without any criticism whatever can come from the management department. And as one knows, the choice of navigational equipment/instruments is not only guided by reasons for sound technical performance i.e.:  
- accuracy and reliability,
- easy use, functioning and maintenance,
- quality of information, etc.

As regards this specific matter, A.Yakushenkov's remark is pertinent. He says that "it occurs sometimes that manufacturing companies try to influence upon I.M.O. decisions through their national delegations of gaining certain economical benefits..." Presently, the same navaid manufacturers are the best "sellers" of the product "Ship of the 21th century."

Finally, the difficulty to exhaust all the deficiencies affecting modern bridges operated by only one man should be stressed. This statement is confirmed by an investigation carried out by the Department of Nautical Studies (Hamburg School Of Nautical Studies) on board the "Ship of the Future" Norasia Samantha where the investigators could at glance detect more than 100 deficiencies.

Despite these facts, it does not make any doubt that this way of operating ships is another step before "Intelligent Knowledge Based Systems'" (I.K.B.S) emergence in the maritime field. These systems are "programmes which provide solutions to complex problems using a structured logical approach and any complete problem solution may involve the use of several programmes interactively or in series."

The provided solutions are based upon known or similar
facts dealt with in the past. I.K.B.S improve their knowledge with the time.

What will be the "after" I.K.B.S.? In other words, "should there be a limit in the use of electronics and automation in modern navigation." (24)
SUMMARY OF THE DISCUSSION

There is obviously a new trend which has already emerged in maritime navigation. It certainly carries a lot of advantages. However, its early implementation without the I.M.O. acceptance is a clear infringement of some legal international rules and regulations concerning safety at sea.

Is this trend promoted by the "tacit acceptance" of I.M.O. Member Parties themselves which have ratified the conventions and put them into force?

Progress never steps backward and mentalities are reluctant to quickly change. Even though developments in technology do not, at their early stage follow preset rules and regulations (rules have to be adapted to technology) the new trend in bridge operation should be considered with great criticism and objectivism.

Are reliability criteria satisfied by all the systems in use in an integrated-automated ship?

"Human skills and technical facilities, human limitations and technical limitations raise the question of the limits of electronics - and of man."(24)

Is the overall performance of navigation, shipping and individuals involved in improved?

Does it provide job satisfaction?
In 1989, there are only a few companies implementing One-Man-Bridge watchkeeping arrangements. Within the next decade(s) starting from now, this would not be a tendency anymore but, rather an accomplished fact which significantly may endanger safety at sea, despite the application of sophisticated technology on board vessels.

The threat of more casualties would be derived from the fact that very sophisticated ships would be acquired as second hand vessels of which the proper and safe manning would hardly meet the international standards. Breakdowns and/or degradation of equipment would simply increase the complexity of systems. And as D.Todd (27) says, "the more complex the system, the more accident-enabling factor or errors there are."

Up to now, any legally binding regulations did not entitle any I.M.O. Member Party to implement One-Man-Bridge watchkeeping arrangement at night.

Therefore, the Administrations of the Countries whose shipping companies are concerned with the system should undertake the necessary steps in order to avoid any violations of international rules and regulations. (I.M.O. Resolution 481) Otherwise, appropriate measures should be taken in order to internationally legalize the system for any type of navigation.

For up to now, only Norway has introduced such a proposal to the Maritime Safety Committee (M.S.C.) which duly rejected it. Another application of the same order but only for trials on small ships has found the M.S.C's approval, and even though "Det Norske Veritas have allocated a Watch 1 Class notation to them, present Norwegian regulations
however do not allow single man operations for large ships."(29)

As for West Germany, the research carried out by the Department of Nautical Studies with the shiphandling simulator "SUSAN" has formulated some recommendations which read as follows:

Conditions for a safe One-Man-Bridge watch at night according to study Froese/Sablowski, "Ein-Mann-Brückenbesetzung bei Nacht", Hamburg Maritime Research, 1987:

- three officers available for bridge watch
- master not integrated in the bridge watch
- "free" sailing conditions, i.e.:
  a) no reduction of visibility
  b) no traffic forcing the officer on duty to observe other ships continuously
  c) autopilot in operation
  d) no risk of grounding
  e) full manoeuvrability
  f) all vital systems available
  g) no sudden measures caused by bad weather to be expected
  h) no special risk for navigation
  i) no accident reported in the area

The research has given significant results concerning One-Man-Bridge operation. However, care should be taken on the fact that simulators cannot "simulate" isolation, homesickness, patterns of social relationships on board modern vessels etc. Therefore, one can assume that the study is not rounded off yet.
CONCLUSIONS AND RECOMMENDATIONS

The extensive use of integrated navigation systems and automation in the maritime field has speeded up a lot of processes in the "State-of Art", as well as improved safety at sea and "ship-shore" communication links.

These developments, associated with advanced computing techniques, remote transfer of data, better control and monitoring systems enabling centralised display of high quality information, are intended to reduce the workload from the navigator on the modern bridge.

A new field of knowledge based upon what is referred to as "Decision Support Systems" has come into being in the interface "man-machine" which needs to further be harmonized in order to optimise the decision-making process. This factor, which plays an extremely important role does not belong to one system only, but to a total integrated-automated "ship-officer of the watch-system" where the final decision is left to the prerogatives of the human being.

Where the human being is affected by fatigue in accomplishing repetitious and/or complex tasks requiring concentration as well as meticulousness, the machine as "information processor" "defies" the most important sources of human weaknesses i.e.:
- stress,
- strain, and
- fatigue.

Therefore, it can endlessly compute and compute so as to bring the machine to "behave" according to already specified assigned tasks.

The man, through the objectives of reducing the workload on his shoulders and getting his work done the most efficient way has extensively developed the machine, associated with very powerful and sophisticated techniques. These possibilities allow the realisation and execution of tasks that were not believed to be feasible a few decades ago.

It is said that the machine is the "slave" of the man. However, no machine obeys the master when he is not able to use it properly and derive maximum benefit from it. This means that the human being has necessarily to cope with the machine and vice versa.

This argument stresses the need and necessity to direct much more efforts towards the area of education and training. As a matter of fact, navigation nowadays is faced with two types of human errors i.e.:

- failure in operation because of inability. This factor is referred to as incompetency.
- failure despite of ability, skills and knowledge. This element may be combined with overcomplacency.
Maritime education and training institutions are much more concerned about preventing the first case from occurring by establishing their standards of education and training. Nowadays incompetency should not be allowed for in navigation.

The second case is much more difficult to cure. However, one can reduce its influence by proper mandatory procedures on board vessels, e.g. mandatory check lists like in air navigation, or by establishing procedure trainings.

This method is used by the shipping company Chevron. As a matter of fact, the crews of Chevron have been trained according to certain specific procedures they have to observe when encountering certain situations. Those procedures are specified by the company and implemented with adequate time of simulator training.

If standards of education and training are kept high in maritime institutions so as to produce very competent seafarers, and if all the shipping companies require the execution of their established procedures which should necessarily comply with international rules and regulations, then the level of safety at sea would certainly be improved. Besides, shipping would substantially gain in efficiency.

However, this requires financial investment without which objectives cannot be reached. This is also why Ray Maybourn (30) evaluates safety at sea with respect to its expensive cost.
There is a word to say to the Developing Countries as regards the new trend in navigation.

Pace should necessarily be kept with developments in technology. That is why integrated navigation and automation, which are up-to-date subjects in modern navigation should be brought to our maritime education and training institutions in order to show basic principles on which the new equipment/instruments are based.

The objectives of these courses would be to provide our trainees with the necessary background for understanding those basic concepts, their principles and shortcomings.

With declining cost of automation and in view of natural evolution, the Developing Countries will also operate modern vessels. This consideration and all others dealt with should constitute the basis for, not only encompassing up-to-date subjects in their curricula, but also allocating to them the necessary importance. And, since integrated navigation is a fundamental aspect of modern navigation, its concepts should be, first of all popularized at the maritime education and training institutions' level.

As regards, we will particularly stress the need for the two West African Regional Maritime Academies (Ecole Regionale Des Sciences Et Techniques De La Mer, Abidjan-Cote-D'Ivoire; Accra Regional Maritime Academy, Ghana.) to include integrated navigation in their curricula.

In West Africa, there is on the one hand the need to harness new techniques in navigation and on the other, the problem of facing the lack of equipment for backing up the
lectures on certain subjects e.g.: integrated navigation systems.

A lot of efforts have been carried out for the improvement of maritime training facilities with the help of I.M.O., especially at the "Ecole Regionale Des Sciences Et Techniques De La Mer" in Abidjan. The institution has been fitted with ARPA simulators, a planetarium etc. The buildings themselves are brand new.

The same needs are present at Accra Regional Maritime Academy of which the training facilities should be improved.

But for both of them, there is no integrated systems available for teaching purposes. This is due to the fact that this type of equipment is very expensive.

However, there is something to be done in order not to lag too far behind the application of new principles and techniques in navigation.

It has been shown that there are justified reasons for the maritime-academies in the Developing Countries to harness modern concepts and techniques whereas, the acquisition of modern navigational equipment/instruments for improving knowledge and skills requires high expenditures generally not feasible by maritime institutions in most of the Developing Countries. The financial problems which they are confronted with should stimulate more concerns about "Cost Effective" training equipment/instruments.

On this point, Hong Kong Polytechnic's and Rimouski (Canada) Maritime Academy's examples are remarkable.
Both of them have connected TV screens to a configuration of fully equipped radar simulators with own ship stations in order to obtain an outside view. The same principle has been utilised at the Seamen's Church Institute of New York and New Jersey (United States of America) with the difference that, instead of TV monitors, "PC" screen computers have been used. But the effect is the same.

These examples represent what is referred to as prototyping. It consists of acquiring sub-systems and improving them along with time and experience.

For better understanding of "Cost Effective Visuals", refer to Samar Sing's (31) and Stanley C.F. Chang's (31) article presented at the Fifth International Conference on Education and training. (32)

For showing the basic principle of filters which play an important role in integrated navigations systems, "PC" computers can be utilised due to the fact they can, better than the human being perform repetitious tasks such as, for instance recursive computations extensively used within the Kalman Filter algorithm.

Recently, Computers have been introduced to the "Ecole Regionale Des sciences Et techniques De La Mer D'Abidjan". However, they are yet not used for navigational didactical purposes.

Another concept dealt with in this paper is related to the dual-purpose education scheme.
As regards, there are several factors against the implementation of this scheme presently in West Africa i.e.: 
- surplus of human resources,
- socio-economical realities/patterns,
- attractiveness of seafaring,
- personnel cost of ships' operation is still low compared to the Developed Countries,
- questionable performance parameters of the system.

And as says D.M.Waters (23), "even if the policy objectives are similar, implementation of these objectives is likely to vary according to national education and social patterns."

Our humble belief therefore, is the fact there is no need to implement the polyvalent scheme for the time being.

The great challenge faced by the Developing Countries lays upon Why? When? and How? the educational systems from the Developed Countries should be applied to their realities.

And since maritime education and training offers a broad area for prototyping, much more efforts should be undertaken in order to improve the present situation. This may be achieved by improving the level of co-operation and information exchange among institutions, as well as with the Developed Countries' maritime education and training institutions.

Finally, one should stress the fact that integrated navigation is not a panacea for solving all the problems dealt with by the navigator on the bridge. It is only an efficient means enabling accurate and safer navigation.
The advantages derived from those two factors may be:

- reduction of losses due to navigational casualties,

- compliance with I.M.O. Resolution A.529 pertaining to accuracy of navigation,

- saving in sailing time, and

- economy in fuel consumption.

All these factors are the parameters assessing efficiency of ship's operation.
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