

ANALYTICAL COMPARISON OF DIFFERENT MOORING SYSTEMS

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Abstract text. The number of ships and ports are increasing in connection with growing transportation demand in the world each passing day. And thus the numbers of mooring operations are increasing. Mooring operations are one of the most dangerous operations for ships and ports. Lots of accidents that result in deaths, injuries and financial loss have been lived during mooring operations. Lack of mooring equipment maintenance, untrained and inexperienced personnel, equipment failures, available weather conditions, poor communication, safety procedure errors, risk assessment failure are main factors that triggering mooring accidents that occurred while using conventional mooring system involving ropes and windlass. There have been various innovations in the maritime industry in terms of mooring systems, like the automated vacuum mooring systems, magnetic mooring systems, berthing aid systems, to reduce the hazards associated with mooring operations. Still most of vessels use mooring arrangements involving ropes and windlass. These systems have benefits, as they are flexible and enable berthing at most ports. However, the risks associated with operating conventional mooring system involving ropes and windlass continue to increase as vessels become larger and number of mooring operations increase. In this study, working principles of vacuum based automated mooring system, magnetic mooring system and conventional mooring system involving ropes and windlass will be expressed briefly. Three different mooring systems compared with each other in terms of defined criteria as operation safety, operating cost, maintenance cost, environmental effect, ease of handling, limitations of systems etc. With this study, advantages and disadvantages of vacuum based automated mooring system, magnetic mooring system and conventional mooring system involving ropes and windlass revealed. Analytic Hierarchy Process (AHP) which is a multi-criteria decision making method used for comparison of different mooring systems. The analyses using the AHP method performed by Super Decisions which is a software tool.

Keywords: mooring operation, safety, mooring systems, AHP

1. Introduction

Maritime transport which has lots of high risk, labor intensive and time consuming operations is the most common type of transportation and the backbone of international trade. Technological developments have enabled safer and faster opportunities for various maritime operations. Although mooring and unmooring operations are dangerous, time consuming and labor intensive for ships and ports, conventional mooring systems involving ropes and windlass are still mostly common systems used for mooring and unmooring operations. For a long period conventional mooring system involving ropes and windlass has been used by the maritime industry to secure vessels. It has been a reliable system that has worked well but is now somehow out of synch with the maritime industry's focus on continuous improvements in productivity and efficiency. Failures of conventional mooring systems have been attracted attention nowadays. Especially safety defects of conventional mooring systems have been discussed. Lack of mooring equipment maintenance, untrained and inexperienced personnel, equipment failures, available weather conditions, poor communication, safety procedure errors, risk assessment failure, fatigue are main factors that cause serious injuries and losses. In a report of UK P&I Club Loss Prevention Department, it is stated that major accidents involving mooring equipment in the last 20 years had injured many seafarers and had cost the UK P&I Club over US\$34 million. (UK P&I Club, 2009) Alternative mooring systems such as magnetic mooring system and vacuum mooring system are innovative systems and enable safer and faster opportunities, but these systems are not commonly used. Different mooring systems have advantages and disadvantages. Various options instead of conventional mooring systems are available now. These are vacuum mooring system, shore-tension hydraulic mooring system, dock lock magnetic mooring system and other innovative subsystems. In a study, different mooring systems, shore-based mooring lines, softer fenders, a combination of softer fenders and shore-based mooring lines, vacuum mooring system, shore-tension hydraulic mooring system, dock lock magnetic mooring system were analyzed by means of dynamic mooring simulation. The ship motions for the dynamic mooring analysis were determined with the Baird in-house model Quaysim. This program comprises a time domain simulation to analyze the dynamic behavior of a moored ship subject to combined swell and long waves. The mooring line and fender loads follow from the computed ship motions and the characteristics of the mooring lines and fenders. According to the results, the best reduction of vessel motions and mooring line forces was achieved by installing a combination of pneumatic fenders and constant tension winches set to 30 ton, or nylon breast lines with a

pretension of 25 ton for the study. (Molen, 2015) In a research project, named Alternative Berthing, conventional mooring system, vacuum mooring system and vacuum mooring system were researched and their working principles, advantages and disadvantages were stated in the study. Interviews, desk research and qualitative research methods were tried to collect information. (Bodegom, 2014) In a bachelor's thesis, alternative mooring systems were researched and two alternative mooring systems, vacuum and magnetic, were defined without ropes or lines. Mooring systems were evaluated mostly on the basis of interviews that were carried out by producers of mooring systems. (Himanen, 2016) Different studies about new mooring systems and comparisons by using different methods are available, but analytic hierarchy process method has not been used to compare mooring systems. In this study, conventional mooring system, magnetic mooring system and vacuum mooring system are compared by using analytic hierarchy process method. The aim of this study is to compare different mooring systems in terms of safety, operating cost, flexibility to ship movements and environmental conditions, operating limitations and environmental effect and to decide optimum mooring system.

2. Mooring Systems

2.1 Conventional mooring system

Conventional mooring system involves mooring ropes and windlass. Tension to mooring lines to keep them tight is necessary to hold vessel. Tension is enabled by windlass that may have hydraulic or electric driving motors. Mooring ropes hold the vessel when alongside. Loading and discharging operations, ship movements and environmental conditions such as wind, tide and current changes tension of ropes. Ropes should be at its optimum tension to hold vessel appropriately. More tension may cause breaking of ropes that cause serious injuries or losses. Less tension may cause giving away of vessel from quay. That's why, continuous watch keeping and arranging the tension of ropes according to changing conditions are necessary when alongside. In a conventional mooring system operation approximately six crew necessary onboard and four linemen on shore for handling ropes. Crew number for mooring operation may change according to vessel size. Fore and aft mooring crew get ready before mooring operation. They arrange and plan their ropes and positions for mooring operation. When the vessel approaches to the quay planned ropes are send out to the linemen to be made fast by using bollards on shore. When the vessel is in necessary position at quay all ropes are send out and mooring operation completed.

2.2 Vacuum mooring system

Vacuum mooring system is more complicated and innovative system that has vacuum pads which are used instead of ropes. Vacuum pads have measurable working load, providing safe connections between ship and shore. (Popesco, 2009) When combined with the innovative, three dimensional supporting apparatus, the mooring units emulate the range of movement, resilience and elasticity of a line mooring. When the vessel is a few meters away from the quay the vacuum pump is started up and the vacuum pads suck the ship to the quay. In case of system failure, the system does not lose its vacuum for two hours so there is enough time to work on a leak in the system or to get the power back on. If leakage of vacuum pads is 60% system will give a signal to the crew so they can immediately with the repair so the vessel does not lose its vacuum. A power generator is also a possible solution to prevent a black out of electricity. The vacuum system makes use of a vacuum pump, hydraulic system, steel, monitors and power supply to control the whole system. The system has sensors and monitors that indicate vacuum force, ship movements and alarms. (Bodegom, 2014) This automated ship to shore interface system has been used for mooring at some ports.

Magnetic mooring system

Principle of electromagnetism is used for magnetic mooring system. An electromagnet is a type of magnet in which the magnetic field is produced by an electric current. Electric current is used for making temporary magnets known as electromagnets that work on the magnetic effect of electric current. Combination of a solenoid and a soft iron core constitute an electromagnet. Soft iron should be used to remove magnetism of electromagnet when the electric current is cut off. Electromagnets can be made of different shapes and sizes depending on the purpose for which they are to be used. Laura Himanen explains structure and working principle of the magnetic mooring system that the system has the electrical cables, fenders to protect the quay and vessel, the magnetic pads connected to the hydraulic arms and the power supply that provides the magnetism. Electrical power produces electromagnetic fields turns on the magnets and electromagnetic fields are used for mooring the ship. (Himanen, 2016) Zhang Qiang, Zhou Zhao-xin and Ma Jian state that the magnetic ship automatic lockage device is designed, to improve the existing problem of conventional mooring systems and they calculated the power required for different types of vessels to pass the lock is analyzed, and the relationship between different breadth and power is also listed in their study. (Qiang, 2015)

3. Method

3.1 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a multi-criteria decision making method that was developed by Thomas L. Saaty who states that the factors that are important for that decision are arranged in a hierarchic structure descending from an overall goal to criteria and alternatives in successive levels. He developed this method for measuring tangible or intangible factors through paired comparisons using judgments from a 1 to 9 fundamental scale and resulting in priorities for the factors. (Saaty, 1990) This is structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. This method has different areas of application and used for decision making, in fields such as government, business, industry, healthcare, manufacturing and education. (Saaty, 1987)

AHP method has been used for selection, evaluation, cost and benefit analysis, planning and development, priority and forecasting. If decision making related literature review is made it is possible to find numerous studies in which AHP method has been used. Vaidya and Kumar made a literature review of the applications of AHP that had been used in almost all the applications related with decision-making. More than one hundred application papers reviewed and analyzed in this study. (Vaidya, 2004)

Because of the fact that, the aim of this study is to determine the most suitable mooring system in terms of defined criteria, studies about selection among alternatives were elaborated on. Byun used AHP for deciding on car purchase. Exterior, convenience, performance, safety, economic aspect, dealer and warranty was defined as main criteria for selection and three automobiles were defined as alternatives and the most suitable car was determined in this study. (Byun, 2001). Podgorski used AHP method for prioritization and selection of key performance indicators measuring occupational safety and health management system in his study. (Podgorski, 2014) There are lots of software tools that perform AHP method. One of them is Super Decisions that is user friendly software and it can be accessed easily. This software which was used for implementation of AHP, provides tools to create and manage the method. Super Decisions software also gets results and perform sensitivity analysis on the results. (<https://www.superdecisions.com/tutorials>)

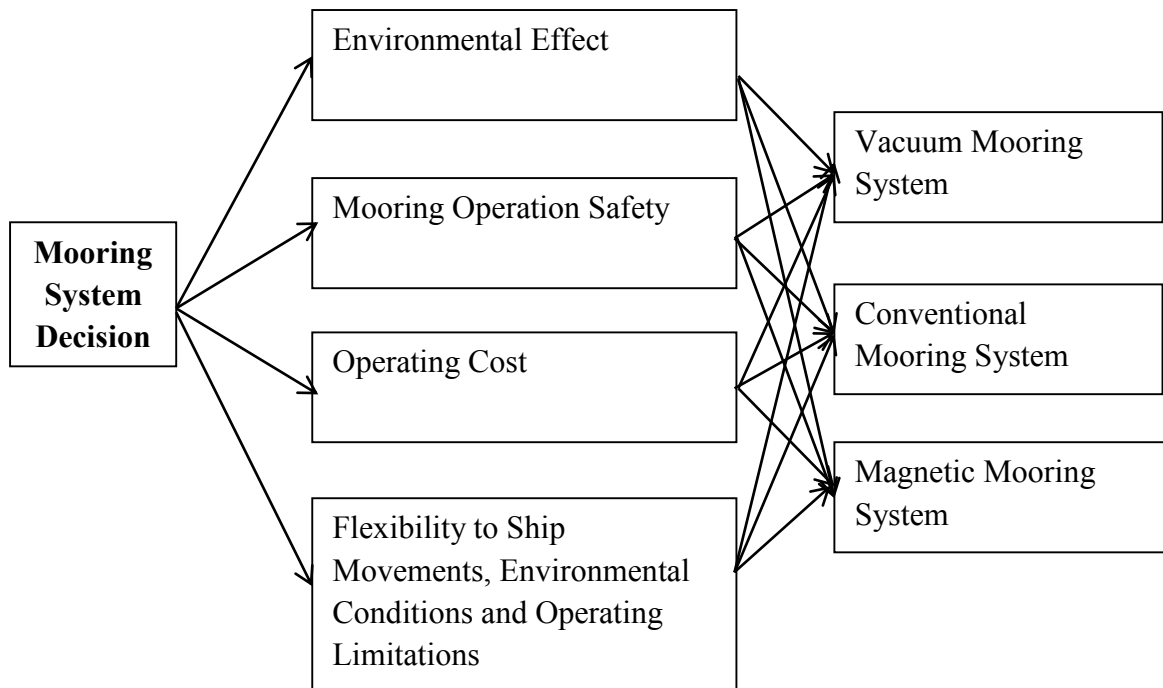


Figure 1: Hierarchical Structure for Mooring System Decision

3.2 Implementation of Analytic Hierarchy Process and Results

For decision making of the most suitable mooring system, three different mooring systems were defined as alternatives. Criteria were defined for comparison of vacuum mooring system, magnetic mooring system and conventional mooring system in terms of safety, cost and environment. Environmental effect, mooring operation safety, operating cost, flexibility to ship movements, environmental conditions and operating limitations were defined as main criteria for analytic comparison. Criterion of flexibility to ship movements, environmental conditions and operating limitations was used for defining which mooring system was more flexible in different environmental conditions such as in big tidal differences, in strong winds and for ship movements due to loading, discharging operation and shifting. Criterion of operating cost was used for defining which mooring system needed less crew for mooring operation, which mooring system needed less cost for maintenance and repair, which mooring system takes less time for completion of mooring operation. Criterion of environmental effect was used for defining which mooring system was less harmful for environment. Criterion of mooring operation safety was used for defining which mooring system is safer and which mooring system was faster and easier to leave from the quay in an emergency situation at port such as fire. For implementation of AHP, pairwise comparisons for the criteria with respect to the goal were prepared and a questionnaire comparison table created by using Super Decision

software. Pairwise comparison is a process that people are able to express their sense of preference or importance with respect to determined criteria. (Saaty, 1987) The Saaty rating scale was used for pairwise comparison.

1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values

Table 1: The Saaty Rating Scale

The Saaty rating scale describes pairwise comparison with the 1-9 ratio scale. Criterion of mooring operation safety should be rated at 5 if a criterion such as mooring operation safety is strongly more important than another criterion such as operating cost and this means that operating cost is more important than mooring operation safety and is valued at 1/5. These pairwise comparisons are carried out for all determined criteria. The results of these comparisons were entered into the comparison table of Super Decision software.

Environmental Effect	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Flexibility and Limitations
Environmental Effect	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Mooring Operation Safety
Environmental Effect	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operating Cost
Flexibility and Limitations	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Mooring Operation Safety
Flexibility and Limitations	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operating Cost
Mooring Operation Safety	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operating Cost

Table 2. The Questionnaire Comparison Table

The questionnaire was applied to 8 participants who are experts in mooring operations and mooring systems. The questionnaire comparison table was created by means of average values that were calculated by using participants' answers.

Inconsistency: 0.07418	
Environmental Effect	0.15118
Flexibility and Limitations	0.26534
Mooring Operation Safety	0.50829
Operating Cost	0.07520

Table 3. The Results of the Pairwise Comparisons

The software calculates inconsistency index for checking the consistency of the evaluations. Small values of inconsistency may be tolerated. If inconsistency index is less than 0,1this is tolerable, and a reliable result can be expected. The inconsistency index that calculated by the software is 0.07418, so correction of judgments is unnecessary.

Name	Ideals	Normals
Conventional Mooring System	0.506956	0.253015
Magnetic Mooring System	0.496700	0.247897
Vacuum Mooring System	1.000000	0.499088

Table 4. The Results for Alternatives

The Normals column presents the results in the form of priorities. The Ideals column is obtained from the Normals column by dividing each of its entries by the largest value in the column. These results show that Vacuum mooring would be the best choice. The “Ideal” column shows the results divided by the largest value so that the best choice has a priority of 1.0. The others are in the same proportion as in “Normals” and are interpreted this way: Magnetic mooring system is 49.7 % as good as vacuum mooring system and conventional mooring system is 50.7% as good as vacuum mooring system.

4. Conclusion

When conventional, magnetic and vacuum mooring systems are compared each of them has different advantages and disadvantages. However, vacuum mooring system has more preferable than the other mooring system according to results of analytic comparison. Conventional mooring system which has been used for years is usual for marine industry, so it has extensive market, suppliers and technical support departments all around the world. It is easy to find technical support or equipment when necessary for the system. Initial investment cost for vacuum mooring system is much more than conventional mooring system. However, operating cost and maintenance cost is less for vacuum mooring system. In terms of safety, danger of injury to linesmen and ship crew due to mooring ropes can be eliminated by vacuum mooring system which can be operated and monitored by one personnel. On the other hand, more personnel are necessary for mooring operation in conventional mooring system, so much more personnel expose to danger throughout mooring operation and also for longer period in contrast with vacuum mooring system that enable fast attachment and instant release. Especially for tanker terminal, vessels may have to leave from quay immediately because of an emergency such as fire or explosion in tanker terminal. Emergency shore leave

for vacuum mooring system is easier and faster than conventional mooring system. Fast mooring also enables less operation of the ship's propulsion, of tugs and lines' boats and consequently diminishes emissions into the port when it is thought from the stand point of environment. As a result, vacuum mooring system has much more advantages. It is understood from this study vacuum mooring system is safer, faster, and more environment-friendly than conventional and magnetic mooring system. For this reason, use of vacuum mooring system should be extended and the system should be developed.

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