Expert Systems with Applications 40 (2013) 3953–3960

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Fuzzy decision support system for ship lock control

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ARTICLE INFO

Keywords:
Ship lock
Fuzzy control
Decision support
SCADA

ABSTRACT

This paper presents the development of a Decision Support System (DSS) for the management of ship locks that relies on fuzzy logic. It contains a brief overview of the history and the construction of locks and basic information related to fuzzy logic, fuzzy linguistic variables and methods used in approximate reasoning. In reality, ship lock control is mostly based on the subjective estimations and the experience of a lock master (ship lock operator). The fuzzy set theory is the most favourable mathematical approach for consideration of indefiniteness and subjective estimates. This paper analyses the control process of a ship lock on a two-way waterway, with one chamber designed for one vessel. A control algorithm is constructed according to a set of linguistic rules that describes the operator's control strategy. The subjective estimations are therefore implemented in the algorithm as fuzzy sets. Fuzzy rules aggregate the final fuzzy set and defuzzification produces a decision. A set of ship traffic data is generated for analysis and simulation purposes based on the annual distribution of ship arrivals at the lock. Two criteria are presented and used in parallel with the Fuzzy DSS (FDSS). These two extreme criteria reflect the interests of shippers on one side and workers and owners of the lock on the other side. These interests occur in actual systems and are used here to evaluate the results obtained using the FDSS. This paper additionally describes the design of the SCADA (Supervisory Control And Data Acquisition) software. This software relies on a PLC (Programmable Logic Controller) and provides a platform on which to implement the desired fuzzy algorithm. The software was developed with the suggestions of operators who have extensive experience in ship lock control. The presented control system can be used for support in decision making in control processes and in the training of new operators of ship locks.

1. Introduction

Ship locks are the most often used structures for surmounting differences in water level created by dam construction on inland waterways. The first artificial waterways date from the era of slavery. They represent the desire of man to adapt the environment to his needs and are an indicator of the degree of development of human society (Dragović, Maksimović, Pantelić, & Pantelić, 2005). Transportation on inland waterways today is one of the most important and most developed forms of transportation.

A lock is a facility for raising and lowering boats between two navigable waterways that are at different levels. On natural inland water flows, there are often obstacles such as rapids, weirs, or dams that prevent free navigation on certain parts of rivers. Locks are used to solve these problems and to bypass the difference in water levels. The organization of vessel traffic on a navigable canal in the zone of a ship lock is a compromise between a rational utilization of the lock and minimizing a ship's delay while waiting to transit the lock (Bačkalić, 2000; Smith, Sweeney, & Campbell, 2009).

There are many types of ship locks. Nevertheless, every lock has three basic elements:

- A lock chamber connects the upper and lower lock approach channels and is sufficiently large to accommodate one or more vessels. The position of the chamber is fixed but its water level can vary.
- A gate that is constructed to be watertight. A gate is often a pair of half-gates at each end of the chamber (Fig. 1). The upper and lower gates are movable and can be opened to permit a vessel to enter or exit the chamber (McCartney, 1998).
- Machinery to empty or fill the chamber as required – valves and pumps, for example.

This paper presents a fuzzy decision support system (FDSS) implemented in existing SCADA (Supervisory Control And Data Acquisition) software that is commonly used at the top of the control hierarchy (Bailey & Wright, 2003). The basic purpose of the SCADA system is to collect important data from the process (Stuart, 2004). Work presented in this paper will extend the function of the

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http://dx.doi.org/10.1016/j.eswa.2012.12.101

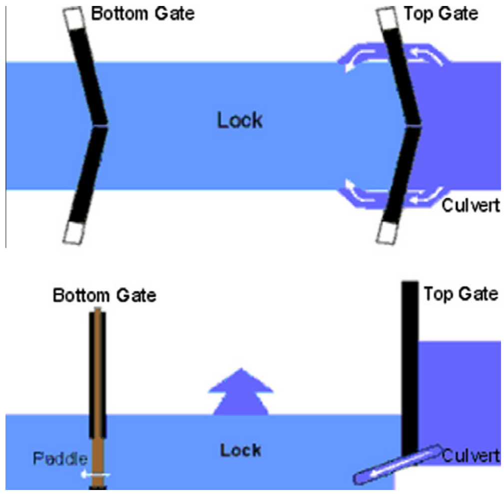

Fig. 1. Plan and side views of a lock.

SCADA system with the proposed expert system, which is designed as a software upgrade to assist lock masters in the decision-making process.

2. Principles of ship lock control

From among the wide variety of ship locks, the effort was narrowed to one specific type of ship lock, but there is no loss of generality as the work presented in this paper is applicable to any other type of ship lock. The most common type of ship lock in Vojvodina (a region of Serbia) is a single-channel servicing system with two independent, stochastic flow requirements for the two opposing directions. Time intervals for the lockage (i.e., passage) process represent one specific ship lock on the DTD (Danube-Tisa-Danube) hydro system. It is assumed that the average time for the lockage of a vessel is 25 min, and the time interval for the change of level in the chamber without a vessel is 15 min. Furthermore, it is assumed that the lock chamber can hold only a single vessel. Based on these time intervals, two possible situations can occur. The first is a "regular lockage," where the vessel enters the end where the gate is open. In this situation, the ship does not have to wait for the water level to change in the chamber. A regular lockage lasts 25 min. The second situation is an "empty lockage," where the ship approaches from the end where the lock gate is closed, and before lockage can take place, the water level in the chamber must be changed. An empty lockage followed by the regular lockage lasts 40 min.

The main objective in the ship lock control problem is a compromise between minimizing the waiting time for lockage and minimizing the energy and water consumption for operating the locks (Ting & Schonfield, 2001). The owners of the lock prefer fewer empty lockages because such lockages reduce the coefficient of utilization of the lock (both in terms of the total number of lockages and in terms of energy consumption). However, shippers prefer to wait as little as possible for lockage. In the case that more ships are approaching the lock on the same end, to reduce waiting times operators have to change the level of the water in the empty chamber, which increases the costs of operating the lock.

3. SCADA software design

The SCADA system collects information from the River Information Services (RIS) such as data on speed, distance and the direction from which the ship is coming. These data are input variables for the FDSS proposed in this paper.

The basic functions of the SCADA software in our case are:

- measurement, data collection and processing,
- management and control of doors, pumps and valves on the ship lock,
- a display of process status and lock status, and
- signalling and alarms in the case of failures and errors.

SCADA software is a reliable system for monitoring and controlling locks. It facilitates the management of the lockage of ships. All necessary data are stored in a database. The software is designed for a PC (running the *Windows* operating system) that is located in the control room. This computer is connected to the process computer (PLC) via an Ethernet communication link using a standard TCP/IP protocol (Clarke & Reynders, 2004) or any other industrial communication protocol (Nikolić, Bugarski, Kulić, & Oros, 2010). Some practical solutions using SCADA systems can be found in (Bugarski, Kulić, Francuski, & Vasić, 2008; Bugarski, Kulić, Jeličić, Vasić, & Oros, 2007; Bugarski & Nikolić, 2009; Bugarski, Nikolić, Francuski, Kulić, & Jeličić, 2009; Bugarski, Nikolić, & Kulić, 2010).

SCADA software follows the functional organization of the ship lock. One main screen (Fig. 2) from which operator can monitor the entire process is displayed on the PC when the application runs. This figure shows the complete lockage process. Left-clicking the computer's mouse on any machine opens a small window that enables the control of that machine. This window contains a position number, the states of the motor protection switches and visual and textual indicators of the state of the machine itself. There are also the buttons for starting and stopping the engine.

Apart from the main view, the operator can monitor the situation with trends of analogue values, a view that displays all alarm massages, a separate image for monitoring the engine operation hours and a view that presents the consumption of the drives.

4. Database of ship arrivals

A unique set of ship arrivals is generated for the simulation. This set can be considered as a ship traffic database. A single data point in the database (one ship arrival) consists of two elements: the time at which the ship reaches the lock and on which end it arrives at the lock. The time of arrival can be calculated from the speed and the distance of the ship from the lock (Campbell, Smith, Sweeney II, Mundy, & Nauss, 2007), and this information is available from the RIS. Two variables are essential for the simulation. One is on which end of the lock the gate is open, and the second is the time for the lockage of a vessel. In this research, the lockage time is as assumed to be constant and the same for all ships (25 min for a regular lockage and 15 min for a water level change in the chamber without a boat).

The number of ships arriving at the lock varies during the day, the week and the month of the year. In the case of the DTD navigable canal network, there is annual cessation of navigation from the 21st of December to the 21st of March, which is included in the construction of the set of arrivals. On other days, the traffic load is approximately 10 ships per day. This research later covers a very large spectrum of ship arrivals, from very low traffic (5 ships per day) to very high traffic (50 ships per day). Random values are added to the nominal number of ships per day. This process introduces a stochastic attribute to the number of ships that already depends on the month. There are a total of 2786 generated arrivals at the lock (presented by month in Table 1 and Fig. 3).

5. Fuzzy control system for operating a ship lock

Successful control of a system usually requires knowledge of the nature of the process and a suitable control algorithm for