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CRITICAL SUCCESS FACTORS OF SCADA SYSTEM IMPLEMENTATION PROJECTS FOR INTEGRATED WATER RESOURCES MANAGEMENT

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Abstract. *The key to successful project management is a systematic approach based on the analysis of critical factors that a project manager must take into account, usually in a form of checklist. This paper shows how to determine CSFs (Critical Success Factors) to construct SCADA (Supervisory Control and Data Acquisition) systems for IWRM (Integrated Water Resources Management) as one of ICT projects that hardly have a clear definition of success, and mostly end with failure. Literature reviews for various perspectives on CSFs and criteria for the construction of a SCADA system were conducted in this study. The opinions of domain experts in SCADA system implementation projects were also reflected through brainstorming to construct an evaluation model which consists of 4 dimensions, 18 variables, and 82 factors to assess the success of SCADA project. An AHP (Analytic Hierarchy Process) study over experts has been conducted to decide weight values and priorities of the model constructs. Suggested model has its value that it is an integrated model of expertise with literature survey to easily assess the possibility of success of SCADA project in an organized way.*

Keywords: IWRM, SCADA, Project management, Critical success factors

1. **Introduction.** To realize a new water management paradigm, a foundational ICT system for IWRM (Integrated Water Resources Management) that maximizes the utility of water resources needs to be established. This ICT system which is commonly known as SCADA system plays an important role in directly connecting the physical realities into the virtual world. This system processes various real-time data that are transferred from the field equipment like sensors to the remote server via network, and executes control commands that are issued by human operators. Even with this powerful features and versatile functionalities of current SCADA system, lots of SCADA construction projects have not been successful because of schedule delay, cost overrun, poor requirement management, and lost revenue. In addition, the definition of success is even ambiguous [5,7]. Thus, a systematic approach to analyze the variables that lead to success or failure of the SCADA projects is worth studying to understand the very nature of those projects. And managing SCADA project by the checklist of CSFs (Critical Success Factors) obtained from this approach will be helpful to achieve the strategic mission of hosting organization. This will shape the SCADA project into a continuously manageable one, and thus the technical performance goals of a project such as time, cost, and scope will be more likely achievable [1,9]. Subjective opinions of domain experts should also be aggregated and considered to help project stakeholders carry out more clear decision making. To derive

CSFs of SCADA project for IWRM implementation while meeting above requirements, the following efforts have been conducted in this research. First, authors have derived several CSFs of the SCADA system implementation project through literature survey, which is briefly summarized in Table 1. Second, the opinions of experts who have experiences in SCADA project for water resources management are incorporated into the literature survey result during a brainstorming session. Third, in order to derive comprehensive CSFs covering not only project management itself but also technical aspects, long and middle term vision, various stakeholders' position, and external environments, a multi-dimensional system that hierarchically organizes detailed items of CSFs is constructed. The weights and priorities of those items are quantitatively derived from our AHP study.

Table 1. Literature reviews and key findings

Subject	Ref.	Key Findings
Project Management	[9] [12]	Management Methodology & Maturity, Scope, Cost, Schedule, Project Manager (Personnel) & Sponsor Information, Deliverables, Progress Measurement, Training Program
Project Management Office	[10]	Personnel Effectiveness, Cognitive Capability, Goal Orientation, Leadership, Problem Solving, Project & Domain Knowledge, Behavior, Strategic & Analytic Thinking
4-level Project Success Framework	[8]	Context & Externalities Level, Business Level, Products & Deliverables Level, Project Process Level
Framework for CSFs of ICT	[21]	Project Context, Institutional Context, System Quality, Information Quality, Service Quality, System Use, User Satisfaction, Project Success, Resource, Stakeholder, Management, System, Direction, Environment
CSFs & Management for SCADA Project	[1,2] [4,5] [7]	Skilled Personnel, Proper Documentation, Change Management Procedure, Technology Selection, Project Goal Alignment, Safety Design, Requirement Definition, Costing, Planning, Execution, User Management
Construction Criteria for SCADA System	[3] [20]	Decentralized RTU, Intelligent Pre-processing, Push vs. Pull, Internet Technology, Decentralized SCADA & HMI, Embedded Hardware, Integrated Hybrid Solution, Availability, Security, Scalability & Portability, Remote Communications

The rest of this paper is organized as follows. Section 2 shows related works on CSFs in SCADA project particularly for integrated water resources management. In Sections 3 and 4, conducted AHP study method and its result are explained in detail. Finally in Section 5, conclusion and contribution of this paper are briefly described.

2. **CSFs in SCADA Project for IWRM.** It may be natural to incorporate hierarchical structure for decision problems with lots of variables. Researchers working on CSFs in project management have also introduced such hierarchical structure as dimensions to organize lots of variables [8,21]. Subiyakto and Ahlan developed a coherent framework for ICT project environment [21]. It is composed of 18 CSFs under 4 project dimensions, which is summarized in Figure 1 in level two and three of project success structure. In this study, authors further extended this project success structure with 82 CSFs at the 4th level. The 82 factors of the CSFs of the SCADA system implementation projects for IWRM were derived through literature research, case studies and brainstorming with 14 people among K-water staff who had professional career (more than 20 years: 3 persons,

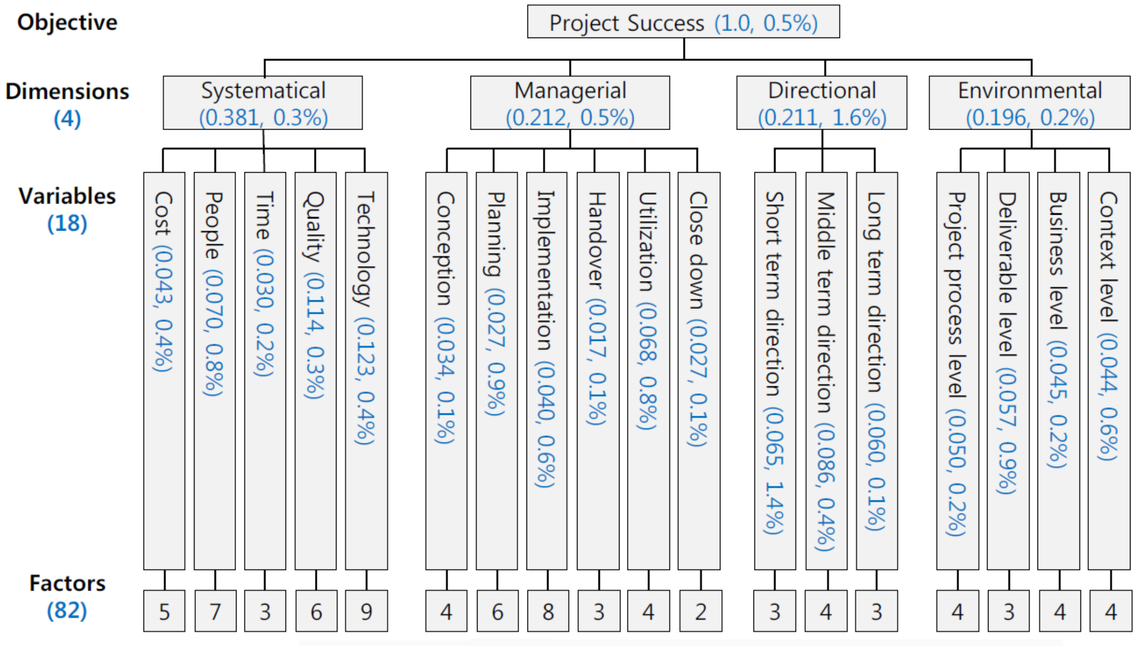

Figure 1. AHP evaluation model of the CSFs with priority and CR value (%)

15 to less than 20 years: 6 persons, 10 to less than 15 years: 3 persons, 5 to less than 10 years: 2 persons) in SCADA system implementation, operation and maintenance.

AHP is a kind of tools for quantifying judgments of the experts through pairwise comparisons [19]. AHP is useful and popular when situations are uncertain or evaluation criteria are diverse. It is a problem-solving and decision-making method that combines subjective judgments with systematic approach. Problems which are difficult to be quantified or complex to model, can be solved by AHP [11]. After organizing the project success structure of SCADA implementation for IWRM in Figure 1, authors conducted an AHP study to evaluate the model, and to relatively prioritize 82 factors.

3. **AHP Study Settings.** To evaluate suggested model, 9-point scale AHP study was conducted in this paper. AHP template (version 07.06.2015) made by K.D. Geopel was used as a tool for this study [6]. Survey questionnaires were distributed to 44 K-water staff members who had professional experiences on implementation, operation or maintenance of SCADA systems in the field of water resources management such as the integrated operation system, remote monitoring and control system, and flood warning system. Out of 44 requests, 16 answers were received. Among them, the survey results of 15 people that had the CR (Consistency Ratio) values within 0.1 (10%) are actually used for this study. The sample size between 10 to 15 people is known to be sufficient for AHP application when the population is from the homogeneous group, and they all have practical knowledge and professional experiences on the application domain [10]. Considering the fact that selected people are K-water staff members with years of experience on SCADA project for water resources management, the sample size of 15 people can be acceptable for this AHP study. Work experiences and positions of the 15 respondents are summarized in Table 2.

Saaty proposed the use of CR value to check if respondents' opinions are consistent in their scoring. The inconsistency of respondent is acceptable when the CR value is less than or equal to 10% [6,19]. In Figure 1, the CR values of questionnaires are given as % values within the parenthesis of each listed item. All the CR values in the figure are less than 10% and overall dimensions' CR value is calculated to 0.5% at the top level, which implies that the respondents' opinions of this research are consistent and reliable.

Table 2. Work experiences and positions of the 15 respondents

Position Experience	5 to less than 10 years	10 to less than 20 years	More than 20 years	Total
Manager	1	1	0	2
Senior Manager	0	9	4	13
Total	1	10	4	15

4. **The Results of AHP.** The weight values of dimensions were investigated as 'systematical dimension (0.381)', 'managerial dimension (0.212)', 'directional dimension (0.211)', and 'environmental dimension (0.196)' as is listed in Figure 1. However, the influence for the project was originally in the order of 'environmental dimension', 'directional dimension', 'managerial dimension', and 'systematical dimension' [8]. It is notable that the order of weight values for dimensions is exactly the reverse of influence order which was given in the previous research. This difference can be explained from the time phase of project. External factors such as environmental and directional dimensions may hugely influence project on its build time. Once the project is initiated, project participants implicitly recognize those external factors of project are determined and cannot be changed by themselves although the impacts are bigger than the others. Consequently, they may think the controllable internal factors such as systematical and managerial dimensions more highly than the fixed external factors when the project is running. Out of 18 variables in Figure 1, the 5 most weighted variables are 'technology (0.123)', 'quality (0.114)', 'middle term direction (0.086)', 'people (0.07)' and 'utilization (0.068)'. The 5 least weighted variables are 'handover (0.017)', 'planning (0.027)', 'close down (0.027)', 'time (0.030)', and 'conception (0.034)'.

4.1. **Weight values of 82 factors.** All 82 factors that are identified in this study are summarized in Table 3, and their weight and priority values are listed in the parenthesis. Each factor also has a bracket after the parenthesis that indicates its references from where it is mentioned as an important factor for SCADA project implementation. Some factors without references are identified by 14 experts while brainstorming the model. All the weight values in Table 3 are rounded off at the 4th decimal point below zero for brevity. So the same weight values with different priority may occur between factors.

4.2. **The implications of the results.** The top 32 factors with the highest priority values occupy 60% of the total cumulative weight. Among them, the majority is from directional dimension (10 factors) and from environmental dimension (9 factors). Overall, the factors from directional dimension have higher priorities than those of factors from environmental dimension. The weight and priority values of remaining 13 factors except above 19 factors are as follows: 'standardization and systematization of the system configuration (0.032, 1st)', 'construction quality management (0.022, 6th)', 'Ensure the reliability of the lower level equipment (0.022, 7th)', 'stabilization of the system (0.022, 8th)', 'early detection and corresponding of emergency (0.020, 11th)', 'quality control of the equipment (0.020, 12th)', 'alarm management (0.019, 14th)', 'RCS (TM/TC) selection (0.019, 17th)', 'operation and management (0.019, 18th)', 'selection criteria of application techniques (0.018, 19th)', 'process management (0.015, 24th)', 'creating software (0.014, 26th)', and 'technician ability (0.013, 28th)'.

SCADA system for IWRM needs to be configured over the complex sub-systems and large area. In order to manage resources to be turned on the system more efficiently and to achieve goals effectively, it is necessary to standardize and systematize the system configuration. By thoroughly managing qualities associated with construction and equipment in the course of system implementation, it is possible to meet customer requirements and to increase the satisfaction of stakeholders. If the understructure equipment such as

Table 3. Weight and priority values of 82 factors

Variables	Factors (Weight, Priority) [References]
Cost	Proper budgeting (0.012, 38) [9], To avoid the lowest bid (0.009, 55) [9], Cost management (0.006, 66) [4,9], Risk minimization of new development (0.009, 50) [4], Construction cost information management (0.007, 65) [4]
People	Technician ability (0.013, 28) [2,7], Project organization (0.007, 59) [2,7,9], Project manager (0.009, 52) [9], Authority and responsibility (0.007, 64) [2,9], Provider selection (0.012, 40) [2,9], Ordering organization supervisory service (0.012, 37), Operation and maintenance personnel (0.010, 48)
Time	To eliminate unreasonable delivery schedule (0.007, 58) [2], Schedule (0.008, 56) [4], Process management (0.015, 24)
Quality	Establishment and compliance of the quality control procedure (0.011, 44) [9], Set of work standards (0.011, 41) [12], Quality control of the equipment (0.020, 12) [12], Construction quality management (0.022, 6), Selection criteria of application techniques (0.018, 19) [2,5], Standardization and systematization of the system configuration (0.032, 1) [2,3,5,7]
Technology	HMI selection and management (0.012, 36), Network selection (0.011, 42) [7], Data management (0.012, 34), Creating software (0.014, 26) [5,7], Open architecture (0.012, 35) [7], Ensure the reliability of the lower level equipment (0.022, 7), RCS(TM/TC) selection (0.019, 17), Improvement of duplicated or distributed control level (0.012, 33) [20], Information security (0.007, 61)
Conception	Range setting (0.011, 45) [9,12], Set of success criteria (0.007, 63) [2,5,9], Requirement definition (0.009, 53) [2,4,5,12], The definition of the proposal and contract (0.007, 60) [2,4,9]
Planning	Site investigation (0.005, 70) [4,7], Requirements analysis (0.007, 62) [4,7], Well-designed construction documents (0.003, 81) [7], Project launching (0.003, 82) [2,4,5,9,12], Establishment of emergency measures (0.004, 77) [4,5,12], Commissioning test plan (0.005, 72) [4]
Implementation	Simulation (0.003, 79) [7], Change management (0.004, 75) [2,5], User(stakeholder) participation and management (0.005, 69) [2,5], PDCA cycle execution (0.004, 73) [4,9], Attitude of the ordering party (0.004, 76) [4,5,9], Attitude of the contractor (0.005, 71) [4,5,9], Communications management (0.008, 57) [4,9], Conflict management (0.006, 67) [5,9]
Handover	Commissioning test (0.010, 49) [2,4], Completion inspection (0.004, 78) [2,9], Education and training (0.003, 80) [2]
Utilization	Alarm management (0.019, 14), Early detection and corresponding of emergency (0.020, 11), Maintenance (0.010, 47) [2], Operation and management (0.019, 18)
Close down	Stabilization of the system (0.022, 8), Sharing and management of knowledge (0.006, 68) [5]
Short term direction	Integrated operation management of the entire process of the supply of water (0.024, 4) [13-18], Construction of integrated water information platform (0.021, 9) [13-17], Construction of integrated flood disaster management system (0.020, 13) [13-17]
Middle term direction [13-17]	IWRM-based integrated water management (0.017, 20), Smart Water Grid-based supply of healthy water (0.029, 2), Real-time monitoring of the entire basin water circulation (0.020, 10), Sophistication and the joint use of the integrated water management technology (0.019, 15)
Long term direction [13-17]	Future growth power generation through innovation paradigm of water management (0.017, 21), Realize the public value of public enterprises such as national water welfare (0.024, 5), Through the improvement of productivity and efficiency, provide services that meet the public's point of view (0.019, 16)
Project process level [13-17]	Efficient allocation of water reserved (0.015, 22), Demand customization water supply (0.012, 39), Taking into account the facility utilization efficiency and energy (0.013, 30), Optimization of facility utilization rate (0.009, 51)
Deliverable level [13-17]	Switching how to manage the water from the hardware manner to soft method of using ICT (0.015, 23), Emergence of new technologies in the field of water management such as Smart Water Grid (0.013, 32), Systematization for integrated management of water quantity, water quality, ecology, and environment (0.029, 3)
Business level [13-17]	Water-related comprehensive service industry (0.014, 27), Globalization and specialization (0.013, 31), Privatization and decentralization (0.004, 74), Wide-area and integration (0.014, 25)
Context level [13-17]	Stable water resources (0.013, 29), Smart water resources management (0.010, 46), Safe river to disaster (0.011, 43), Sustainable river (0.009, 54)

floodgates, pumps, and water treatment facilities has poor reliability, then overall system will fail to function properly. By enhancing the reliability of such base equipment while remotely monitoring and controlling, it is possible to achieve substantial project outcomes. In addition to this, the RCS (Remote Control Station) which is connected to base equipment by wiring is responsible for communication and logical control of such base equipment. Therefore, if RCSs are correctly selected and installed, it will be possible to significantly reduce the risk for operation and construction of SCADA system. Clear references for selected techniques to be applied to the system will be also helpful for efficient project design. Once the system goes live after the construction, there may be errors and modifications which are not expected previously. They may introduce potential risks to the system. By discovering those risks at an early stage and thus stabilizing the system soon, it is possible to achieve project objectives and to avoid possible loss that may occur in the future. In this perspective, 'stabilization of the system (0.022, 8th)', 'early detection and corresponding of emergency (0.020, 11th)', and 'alarm management (0.019, 14th)' are closely associated factors. By carefully reviewing and managing above 82 factors in their SCADA implementation project, it is expected to achieve organization's objectives.

5. **Conclusion.** In this paper, overall CSFs for SCADA system implementation projects for IWRM are surveyed and prioritized via AHP study. Authors suggest a hierarchical model that provides multi-dimensional point of views. Suggested model covers various stakeholder's positions, long-term tactics, company's strategic issues, and external environment as well as project management issues and technical aspects. The total of 82 factors and their weight values is also identified by experts' AHP study. The contribution of this study lies in its consistency with previously researched project success structure, and more thorough and systematic evaluation of various CSFs for SCADA project implementation. By carefully managing suggested 82 factors for SCADA implementation, it will be possible to achieve project goals more easily and systematically.

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