Assessing the Influence of Pandrah Irrigation System Performance Indicators Using Structural Equation Modeling

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Abstract – Pandrah Weir, built-in 1987, serves the Pandrah Technical Irrigation Area in Bireuen District, Aceh Province, with an area of 1.203 Ha. Its old infrastructure has experienced various damage that can decrease the irrigation system performance. The Pandrah irrigation system's previous performance assessment by both the MASSCOTE approach and Rapid Appraisal Procedure (RAP) evaluation suggested a service level of 3.05 (useful classification). This study assessed the effect of the variables on the Pandrah irrigation system's performance with Structural Equation Modeling (SEM) operated by the AMOS program. The four leading indicators were irrigation service, Water User Farmers Association (P3A), operator Human Resources (H.R.), and irrigation operation modernization. The refinement of irrigation system performance analysis using SEM showed that results of the four irrigation system performance indicators, namely: 0.082 (p=0.768), 0.090 (p=0.273), 0.419 (p=0.287), and 0.606 (p=0.039) for irrigation service, P3A in indicator, irrigation operation modernization, and H.R. respectively. Based on the evaluation of the four indicators of irrigation system performance, it is concluded that the Pandrah irrigation system's performance is good. This performance assessment provides a clear picture of irrigation water services, H.R., P3A being an initial assessment for priorities, planning, and scheduling to start modernization programs for irrigation system operations. Irrigation modernization aims to facilitate the operation and maintenance by improving the irrigation system. This modernization means that irrigation planning, irrigation operation, maintenance, and monitoring systems have been carefully calculated before proposing a new irrigation network. The success of monitoring activities requires the use of information technology.

Keywords: Irrigation system performance, SEM, AMOS, irrigation modernization.

Introduction

Irrigation is a process of flowing water from water sources to the agricultural system. Irrigation is the process of adding water to meet the soil's needs for plant growth (McCartney et al., 2019). Irrigation is an effort to supply, regulate and dispose of water to support agriculture, including surface irrigation, swamp irrigation, underground water irrigation, pump irrigation, and dike (Government Regulation No. 20, 2006). Exploitation and maintenance of irrigation networks are a series of efforts of regulating water irrigation, including their disposal and the efforts to maintain and secure irrigation networks so that they can always function properly (Ministerial Regulation of Public Work and Housing No. 12, 2015). Therefore, irrigation management is needed not only for technical activities but also for a social institution (Ambler, 1991).

Irrigation institution development has contributed to a shift in rural communities’ institutional and social-economic dynamics, and this phenomenon will continue. The interaction of technology (irrigation) and institutions embodies forming new institutions (Rachman et al., 2002). Irrigation modernization in Indonesia is an effort to realize a participatory irrigation management system oriented to the fulfillment of irrigation service level effectively, efficiently, and sustainably to support food and water security through increasing the reliability of water, infrastructure, irrigation management, managing institutions, and human resources (General Guideline for Irrigation Modernization, 2011). Evaluation of irrigation system performance can also be used as a recommendation to improve and increase irrigation systems’ performance because a good irrigation system can certainly increase the
planning productivity of farmers (Sebayang et al., 2014). Irrigation network performance is influenced by the building's physical condition, the building's function, factors of interest in the management of irrigation networks in the affected area, and the production results (Supadi, 2009).

Similar to the Pandrah Technical Irrigation Area (I.A.), a technical I.A. located in Samagadeng Village, Pandrah Sub-district, Bireuen District, it has an irrigated area of 1,203 hectares. Based on the research result by Tanzil (2012), it was informed that there was a decrease in the efficiency of primary, secondary, and tertiary channels compared to the value of plan efficiency. The efficiency values for primary, secondary, and tertiary channels are 87.50%, 80.01%, and 76.13%, consecutively. The Pandrah irrigation network's total efficiency is 50.30%, showing there has been a decrease of 11.70% from the plan efficiency of 65%. The study of Tanzil (2012) was only the calculation of the irrigation network's efficiency on the Pandrah Kanan Channel, namely by measuring inflow and outflow discharge in the channel. Loss of irrigation water was caused by damaged canals, illegal tapping along the channel, domestic use of households, complementary structures for irrigation, and evaporation.

The Pandrah Weir, established since 1987, serves the Pandrah technical Irrigation Area in Bireuen District, Aceh Province, with an area of 1,203 Ha. Its old infrastructure has experienced various damage that can reduce the irrigation system performance. Indications of low network performance that are often experienced in irrigation network operations include low water distribution efficiency, especially at the tertiary network level, and inaccurate practice of operational irrigation management that triggers improper practice of Operation and Maintenance costs, reducing the network function. All these conditions require a review of its performance. This irrigation performance study is important to give an idea to the government, irrigation managers, and the farming community as the base for consideration in making decisions in implementing irrigation activities.

The Pandrah irrigation system's performance has been assessed in previous research using the MASSCOTE approach and the RAP evaluation, showing a service level of 3.05 (good classification). Meanwhile, this study assessed the effect of variables on the Pandrah irrigation system's performance using SEM operated by the AMOS program. The study with MASSCOTE through the Rapid Appraisal Procedure (RAP) was a fast way to diagnose the channel's critical examinations by operating physical evidence and a limited questionnaire. This method was limited to conducting cross-assessment/mutual assessment between respondents in irrigation management. In contrast, testing with Structural Equation Modeling (SEM) was carried out on more respondents and more questions (Renault et al., 2007). Then, combined aspects for factor analysis and multiple regression, which simultaneously test a series of relationships to determine direct and indirect effects (Playán and Mateos, 2006).

The four performance indicators in the assessment selected include physical and non-physical in operation and irrigation network maintenance. Infrastructure assessment is included in the irrigation service variable and operation (O.P) modernization.

Materials and Method

Administratively, the Pandrah irrigation network irrigates two sub-districts, namely the Pandrah sub-district and Jeunib sub-district, covering 21 Villages (Figure 1). The Pandrah Weir, built-in 1987 and located in Samagadeng Village, Pandrah Sub-district Bireuen District, has irrigated rice fields area of 1,203 Ha. The Pandrah weir is a barrage with two intake door openings: Pandrah primary left channel and Pandrah primary right channel (Figure 2).

This study's population was all parties related to the irrigation system's performance in the Pandrah Irrigation Area, which consisted of 13 technical executives (including echelon officials and a technical executive staff), 1805 OP officer/operator H.R. in the field, and GP3A/P3A. This study used a purposive random sampling method to meet the criteria that support the research. The required basic assumption in SEM analysis is the number of samples meeting the analysis principle. The Maximum Likelihood Estimation technique requires samples ranging from 100-200 samples. Hair et al. (2009) argued that the representative samples in research using SEM analysis should be at least 100 respondents. Recommended sample sizes between 100 to 200 must be used for the Maximum Likelihood Estimation method (Ghozali, 2011).

For the sample to properly represent the population, a standard is needed in determining the sample. So, to determine the number of samples, the Slovin formula was used. Hence, the sample of this research was 95 people. SEM analysis requires samples ranging from 100-200, and accordingly, it was determined the number of samples in this study to be 110 people (Table 1).

Field observations were conducted on respondents of irrigation O.P officers, serving as operators of irrigation system management, and farmer respondents who are members of P3A as beneficiaries of an irrigation management service.
The method chosen to analyze research data was SEM analysis or path analysis technique, operated by the AMOS (Analysis of Moment Structure) program. The numerical methods implemented in AMOS are the most available effective and reliable (Arbuckle, 2011). The technique is used to determine both the direct and indirect influence of a variable on other variables (Hair et al., 2009). The magnitude of the effect of a cause variable (dependent) on the effect variable (independent) is called the path coefficient. The variables taken in this study were independent and dependent variables. The four main indicators were service, P3A, operator H.R., and irrigation operation modernization.

Figure 1. Research location in Pandrah irrigation area.

Table 1. Respondent samples details for data analysis using SEM.

| No | Respondent                                      | Frequency |
|----|-------------------------------------------------|-----------|
| 1  | Head Branch of Pandrah Irrigation               | 1         |
| 2  | Pandrah’s LA Office Technician                  | 4         |
| 3  | Pandrah’s I.A. Irrigation Technician/Orderly    | 1         |
| 4  | Pandrah’s Weir Operation Officer                | 1         |
| 5  | Pandrah’s I.A. Sluicegate Officer               | 5         |
| 6  | Farmer (Member of GP3A/P3A)                     | 97        |
|    | **Total Respondents**                          | **110**   |
Figure 2 (a) Pandrah Weir, (b) Pandrah primary left channel, (c) Pandrah primary right channel.
The path diagram is a set of measurement models and structural models given in Figure 3. The structural equation expresses the causality relationships between various constructs, and the equation is as follows (Hair et al., 2009):

\[ Y = \gamma_1 X_1 + \gamma_2 X_2 + \gamma_3 X_3 + \gamma_4 X_4 + e \]  

with: \( Y \) = irrigation system performance, \( X_1 \) = irrigation service, \( X_2 \) = P3A, \( X_3 \) = operator HR, \( X_4 \) = channel operation modernization, \( \gamma_1, \gamma_2, \gamma_3, \gamma_4 \) = path coefficient, \( e \) = error of measurement.

![Figure 3. The path diagram of the structural model.](image)

The indexes used to assess the Goodness of Fit of the SEM model provided in Table 2.

| Size Index Criteria | Reference Value |
|---------------------|-----------------|
| Chi square (\(\chi^2\)) | \(\geq 0.05\) |
| p-value | \(\geq 0.05\) |
| CMIN/df | \(\leq 2.00\) |
| RMSEA | \(\leq 0.08\) |
| GFI | \(\geq 0.90\) |
| AGFI | \(\geq 0.90\) |
| TLI | \(\geq 0.90\) |
| CFI | \(\geq 0.90\) |

Source: Hair et al. (2009)

The research hypothesis testing was carried out based on the value of the Critical Ratio (C.R.) and a causal relationship from the analysis of Structural Equation Modeling (SEM) (Margaret et al., 2017). Testing the relationship between the two variables was based on C.R.’s value with probability (p < 0.05). If the value meets the requirements, the hypothesis is accepted with a positive variable correlation.

Results

This section provides some sections of analysis results. The preliminary analysis results show that the SEM analysis was not fit and was not meet the predetermined goodness of fit criteria. To improve the fit model, the initial
review is that the significance of the estimated standardized loading parameters below 0.50, so the indicator must be dropped. However, the model still did not meet the predetermined goodness of fit criteria, and then it was modified following modification indices. Model modification is done seven times to get a fit model. The analysis of the following was revised, and the modified SEM full model are presented in Figure 4.

![Figure 4. Analysis of full model structural equation modeling (SEM) revision and modification.](image)

From the analysis of the revised and modified full model Structural Equation Modeling (SEM), the results of the path analyzer equation are:

\[ Y = 0.802X_1 + 0.090X_2 + 0.419X_3 + 0.606X_4 + 0.13 \]  

(2)

The Confirmatory Factor Analysis (CFA) results of each variable that meets the Goodness of Fit criteria are presented in Table 3.

| The goodness of Fit Indices | Reference Value | Analysis Results of Each Variable |
|-----------------------------|------------------|-----------------------------------|
|                            | Irrigation Service | P3A | Operator H.R. | Channel Operation Modernization | Irrigation System Performance |
| Chi square (\( \chi^2 \))   | \( \geq 0.05 \)    | 2.518 | 1.123 | 4.208 | 25.936 | 41.391 |
| p-value                     | \( \geq 0.05 \)    | 0.284 | 0.570 | 0.520 | 0.168 | 0.038 |
| CMIN/df                     | \( \leq 2.00 \)    | 1.259 | 0.561 | 0.842 | 1.297 | 1.533 |
| RMSEA                       | \( \leq 0.08 \)    | 0.049 | 0.000 | 0.000 | 0.052 | 0.070 |
| GFI                         | \( \geq 0.90 \)    | 0.989 | 0.995 | 0.985 | 0.945 | 0.928 |
| AGFI                        | \( \geq 0.90 \)    | 0.946 | 0.975 | 0.954 | 0.901 | 0.879 |
| TLI                         | \( \geq 0.90 \)    | 0.982 | 1.008 | 1.023 | 0.952 | 0.948 |
| CFI                         | \( \geq 0.90 \)    | 0.994 | 1.000 | 1.000 | 0.966 | 0.961 |

The probability p-value 0.038 is not fit, but the chi-square Chi-square is sensitive to the sample (Ghozali, 2011). Therefore, it is reviewed against other fit criteria, namely TLI and CFI. All values indicate the fit value, which
The goodness of fit criterion is marginal if the value does not meet but not far from the recommended value. The factors that cause it to be marginal include the number of samples, the suitability of the models being built, and those tested. This research requires hypotheses to test based on the Critical Ratio (C.R.) of the causal relationship from the Structural Equation Modeling (SEM) analysis, as illustrated in Table 5.

Table 5. Hypotheses test.

|                   | Estimate* | S.E.** | CR*** | P**** |
|-------------------|-----------|--------|-------|-------|
| Irrigation_Performance <--- Irrigation_Service | 0.082     | 0.276  | 0.295 | 0.768 |
| Irrigation_Performance <--- P3A | 0.090     | 0.082  | 1.096 | 0.273 |
| Irrigation_Performance <--- HR | 0.419     | 0.394  | 1.064 | 0.287 |
| Irrigation_Performance <--- Modernization | 0.606     | 0.294  | 2.060 | 0.039 |

*)Estimate is the value of the relationship between variables; **) S.E. is the standard error; *** C.R. (Critical Ratio) is a certain standard deviation ratio of the mean, standard deviation value; **** P is probability.

Discussion

This Research on Pandrah irrigation system performance using Structural Equation Modeling (SEM) was carried out by developing a model to analyze the effect of irrigation service, P3A, operator H.R., and channel operation modernization on irrigation system performance. Irrigation service has a positive effect on the irrigation system performance (b=0.082; p=0.768). Irrigation services at each level of the channel is starting from the well-maintained condition of the Pandrah weir, the ease of operation of the distribution structure and gauge structure measuring the water flow, the general condition of the channel, the availability of inspection roads along the channel, the communication pattern run by the operator, the flexibility of water delivery, the water reliability and fairness in water delivery positively influence the irrigation system performance. This means that the better irrigation infrastructure and the better communication patterns of operators and water users, the higher the irrigation system performance (Plusquellec, 2009). The condition of infrastructure has decreased due to old age, but it is still good in terms of function because it can provide good service. Every year the infrastructure is maintained by carrying out rehabilitation and maintenance. However, the available budget is limited.

Water User Farmers’ Association (P3A) has a positive effect on irrigation system performance (b=0.090; p=0.273). The legal status of P3A institution, participation in water distribution, enforcement of rules, and good organizational financial competence have a positive effect on irrigation system performance. This means that the better the P3A institution, the higher the irrigation system performance. Operator H.R. also has a positive effect on the irrigation system performance (b=0.419; p=0.287). The operator’s ability and knowledge on the irrigation operation and maintenance, good explication of rules and provisions of instructions from superiors have a positive
effect on the irrigation system performance. This indicates that the higher ability and knowledge of human resources, the higher the irrigation system performance.

In addition, Channel operation modernization has a positive effect on irrigation system performance (b=0.606; p=0.039). In this study, the modernization operation variable shows a probability value of a p-value below 0.05 (0.039) in Table 5. Because modernization is in the Pandrah irrigation area has not been carried out. However, this variable has a positive effect, meaning that the irrigation network's physical condition supports the modernization of the irrigation system. The overall condition and maintenance of infrastructure (as of weirs as well as primary, secondary, and tertiary channels), the availability of O.P equipment, the volume measurement, and control of water deliveries, the flexibility and reliability of water deliveries to reach the most downstream levels, the ability and knowledge of operator and the reliability of operator communication have a strong positive effect on irrigation system performance. Therefore, the better the channel operation modernization, the higher the irrigation system performance.

The study results are in good agreement with Djuwito et al. (2015), which was reported that the physical condition of the channel, management, institutional organization, and human resources have a positive effect on irrigation performance. Furthermore, Sebayang et al. (2014) stated that irrigation network infrastructure, water sufficiency, accuracy in obtaining water, human resources, and farmer institutions positively influence irrigation performance. Mulyadi et al. (2014) found that irrigation service, Water User Farmers Association, human resources, and channel operation modernization have a positive impact on irrigation system performance.

The four dependent variables are the irrigation services, P3A, operator H.R., and operation modernization. The latter has the strongest influence on the irrigation system's performance. It indicates that the modernization of operations, ranging from the availability of water, irrigation facility and infrastructure, irrigation management system, irrigation management institution, and the human resources of irrigation operators, describes a good irrigation system's performance.

Conclusion

Research on the Pandrah irrigation system performance using the structural equation modeling (SEM) was carried out by developing a model to analyze the effect of irrigation service, P3A, operator H.R., and channel operation modernization on irrigation system performance. The results of four hypotheses tests show that all four variables (irrigation service, P3A, operator HR, and channel operation modernization) have a positive effect on irrigation system performance (b=0.082, p=0.768; b=0.090, p=0.273; b=0.419, p=0.287; and b=0.606, p=0.039, respectively). Based on the four dependent variables positively influencing the irrigation system performance, it can be concluded that the Pandrah irrigation system performance is good.

The indicators adopted from the MASSCOTE theory, which are only four, and can assess irrigation performance compared to Ministerial Regulation of Public Work and Housing Number 12/PRT/M/2015 with six parameters to assess irrigation performance. Moreover, with these four indicators, we can find out whether the irrigation is ready for modernization planning or not.

The SEM analysis shows that the operation modernization variable has the strongest influence on the irrigation system performance. This finding indicates that the modernization of operations describes the performance of a good irrigation system. It also allows the planning and scheduling to begin projects on irrigation channel operation modernization to support food and water security.

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Appendix:

Irrigation Service Variable (X)  
X1 Operators of water gates (weirs and gates in channels) to meet the target of irrigation water services  
X2 Operators communicate with (interpreters/observers) or their superiors  
X3 Operators communicate with lower level or fellow operators  
X4 Leaders (direct supervisor) visit the irrigation channel and communicate with operator  
X5 Presence and remote monitoring radio frequency  
X6 Availability of inspection roads along the channel  
X7 Travel time from observer's office to the furthest point along the channel  
X8 Measurement of channel water volume before it is received in the rice field  
X9 Measurement the water volume at the end of water gates  
X10 Obedience of the irrigation operator to deliver water from the permitted condition  

P3A Variable (X)  
X11 Effect of the P3A in the water delivery schedule according to the needs requested by farmers  
X12 P3A’s reliability in enforcing the agreed water distribution rules  
X13 Institutional legal position of P3A  
X14 Financial capacity of the P3A institution  
X15 Participation in water distribution from P3A institutions  

Operator H.R. Variable (X)  
X16 Ability and knowledge of operator provided by Observers and Interpreters  
X17 Employees/operators are encouraged to make decisions  
X18 Management's authority to terminate employees for various reasons  
X19 Operator understanding of the appropriate operation and maintenance
Clarity and specificity of instructions for operator

Channel Operation Modernization Variable ($X_i$)

- **X20**: Clarity and specificity of instructions for operator.

- **X21**: Maintenance of entire infrastructure (Weirs, Primary channels - Secondary channels - Tertiary channels).
- **X22**: Maintenance in all channels (Primary channel - Secondary channel - Tertiary channel).
- **X23**: Reliable operator communications (via telephone or H.T. radio).
- **X24**: Maintenance level of floors and drains side.
- **X25**: Conditions along the channel.
- **X26**: Availability of operation and maintenance equipment and staff will be able to maintain channel function.
- **X27**: Check along the channel.
- **X28**: Guarding of tools and parts of irrigation structures.
- **X29**: Availability of employees/operators with written work rules.

Irrigation System Performance ($Y$)

- **X30**: Dividing the water to the rice fields.
- **X31**: Flow rate of water in all channels (primary channel - secondary channel - tertiary channel).
- **X32**: Weir operation responds to realization of water delivery related to mismatched water delivery.
- **X33**: The effectiveness of a water delivery procedure based on the quantity of water requested.
- **X34**: Water flexibility received in rice fields.
- **X35**: Reliability of the water received in the rice field.
- **X36**: Fairness of water delivery received in rice fields.
- **X37**: Water flexibility of downstream divider gate.
- **X38**: Reliability of water from the downstream gate.
- **X39**: Fairness of water delivery from the downstream gate.