



# Expert System for Identification of Digital Transformation Maturity Level in Secondary Schools Using Forward Chaining

Rizki Nur Afifah

Department of Informatics Engineering, Universitas Islam Negeri Sultan Syarif Kasim Riau, Pekanbaru, Indonesia

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## Abstract

The rapid growth of digital transformation in education has significantly influenced secondary schools through the adoption of e-learning platforms, digital administration systems, and smart classroom technologies, making digital maturity an essential aspect of modern educational development. However, many schools still lack a structured and standardized approach to measure their level of digital transformation maturity, resulting in assessments that are often subjective and inconsistent. This study aims to develop an expert system for identifying the digital transformation maturity level of secondary schools. The system is built using a rule-based approach supported by a knowledge base derived from expert interviews and relevant literature, including established digital maturity frameworks. Data collection is conducted through structured questionnaires that capture key indicators such as ICT infrastructure, teacher digital literacy, digital learning adoption, and institutional policy support. The inference mechanism employed in the system is Forward Chaining, which processes input facts and applies IF-THEN rules to generate logical conclusions. The system is capable of classifying schools into predefined maturity levels, ranging from initial to advanced stages of digital transformation. The results indicate that the expert system can effectively evaluate and categorize digital maturity levels in a systematic and consistent manner. In conclusion, the proposed system provides a reliable decision-support tool that assists school administrators and policymakers in assessing and improving digital transformation readiness in secondary education institutions.

## Corresponding Author:

Rizki Nur Afifah

Department of Informatics Engineering,

Universitas Islam Negeri Sultan Syarif Kasim Riau, Pekanbaru, Indonesia

Jl. H.R. Soebrantas KM. 15 No. 155 Tuah Madani Kec. Tuah Madani – Pekanbaru 28298 PO Box. 1004 Telepon

(0761) 562051; Faksimili (0761) 562052

Email: [nurafifah@gmail.com](mailto:nurafifah@gmail.com)

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## 1. Introduction

Digital transformation in education has experienced rapid growth in recent years, driven by advancements in information and communication technologies and the increasing demand for more efficient, flexible, and accessible learning environments. Secondary schools are among the institutions that have significantly adopted various digital innovations, including e-learning platforms, digital administration systems, and smart classroom technologies. These innovations are not only changing

the way teaching and learning are conducted but also reshaping school management and educational governance. In this context, digital maturity becomes an important concept, as it reflects the extent to which a school has successfully integrated digital technologies into its academic and administrative processes in a sustainable and effective manner.

Over the past decade, research on digital transformation in education and maturity assessment models has significantly increased, driven by the rapid adoption of educational technologies and the need to evaluate institutional readiness. One of the foundational contributions in this field is the development of digital maturity models for educational institutions, which aim to assess the level of integration of digital technologies within organizational processes (Ifenthaler & Egloffstein, 2020). For instance, Carvalho, Pereira, and Rocha (2018) conducted a systematic review of maturity models in education information systems, highlighting that most models focus on higher education institutions and rely on multi-dimensional indicators such as governance, technology, and organizational capability. Their study emphasizes the need for standardized frameworks that can be adapted to different educational levels, including secondary schools.

Similarly, Aleem, Capretz, and Ahmed (2017) introduced a Digital Game Maturity Model (DGMM), which, although focused on software development, contributes conceptually to maturity-based assessment systems. Their work demonstrates how structured questionnaires and rating systems can be used to evaluate process maturity, which later inspired maturity evaluation approaches in other domains, including education.

In the context of education-specific transformation, the OECD Digital Education Outlook (2023) provides a comprehensive global perspective on how digital technologies are reshaping education systems. OECD (2023) highlights that digital transformation in education involves ecosystem-wide changes, including teaching practices, governance, and data-driven decision-making. However, the report also notes that many education systems are still in transitional stages and lack standardized maturity assessment tools to measure progress consistently.

More recent studies have focused on developing digital maturity models specifically for secondary and vocational education. Setiawan, Yarmanto, and Kustiawan (2023–2024) developed digital maturity instruments for vocational high schools in Indonesia, identifying key dimensions such as management, human resources, technology infrastructure, and learning processes. Their findings confirm that schools often operate at varying levels of digital readiness, and structured assessment tools are essential for policy and strategic planning.

In another study, Yarmanto et al. (2024) further refined digital maturity measurement instruments for vocational schools, emphasizing the importance of validated indicators and structured scoring systems. Their work strengthens the argument that education institutions require reliable measurement frameworks to evaluate digital transformation systematically.

Additionally, Bisri, Husen, and Suparno (2024) proposed a digital transformation maturity model for higher education in developing countries. Their research highlights that leadership, institutional readiness, and stakeholder collaboration are critical determinants of digital maturity. Although focused on universities, their model provides a relevant conceptual foundation that can be adapted to secondary school contexts.

From a methodological perspective, expert systems have been widely applied in decision-making systems across various domains. Forward Chaining, in particular, is a rule-based inference technique that starts from known facts and applies logical rules to reach conclusions. Michel and Pierrot (2024) explored models for assessing teacher digital maturity and emphasized that rule-based systems can effectively structure expert knowledge for diagnostic purposes. However, they also noted that such systems remain underdeveloped in compulsory education settings.

Despite the increasing adoption of digital technologies in education, many secondary schools still face challenges in assessing their level of digital transformation maturity (Begicevic Redjep et al., 2021). At present, most evaluations are conducted manually based on observations, questionnaires, or expert judgment. These conventional approaches tend to be subjective, inconsistent, and lack standardized measurement criteria. As a result, schools often find it difficult to obtain accurate and comparable

information regarding their digital readiness, which can hinder strategic planning and policy development in educational digitalization.

From a research perspective, there is still a significant gap in the development of automated and intelligent systems for assessing digital maturity in education (Begicevic Redjep et al., 2021). Although expert systems have been widely applied in various decision-making domains, their application in evaluating digital transformation maturity in schools remains limited. In particular, the use of the Forward Chaining inference method as a rule-based reasoning approach in educational maturity assessment has not been extensively explored. This indicates a need for a more structured and knowledge-based system that can formalize expert reasoning into computational rules for consistent evaluation.

The main objective of this study is to develop an expert system that can identify the digital transformation maturity level of secondary schools. The system is designed to apply the Forward Chaining inference mechanism, which allows reasoning to be conducted based on a set of predefined rules and input facts (Grosan & Abraham, 2011). Through this approach, the system is expected to assist schools in evaluating their digital readiness more accurately, systematically, and efficiently, while reducing subjectivity in the assessment process.

The scope of this research is limited to secondary schools and focuses on key indicators of digital transformation maturity. These indicators include ICT infrastructure, human resource competence, curriculum integration of digital technologies, and institutional governance support (Kampylis et al., 2015). By focusing on these dimensions, the system aims to provide a comprehensive evaluation framework that reflects the overall level of digital transformation maturity in secondary education institutions.

## 2. Research Methodology

This study employs a structured methodological approach to develop and evaluate an expert system for identifying the digital transformation maturity level in secondary schools. The methodology is designed to ensure that the system is built based on validated expert knowledge and is capable of producing accurate and reliable decision-making outputs.

The research design used in this study is Research and Development (R&D) or a Decision Support System (DSS) development approach (Lee et al., 2017). This approach is appropriate because the primary objective is not only to analyze a phenomenon but also to design, build, and test a functional system that can support decision-making processes in educational institutions. Through this approach, the development process follows iterative stages, including analysis, design, implementation, and evaluation of the system.

The knowledge acquisition phase is conducted to gather relevant expert knowledge that will form the foundation of the system. This process involves interviews with education experts, ICT coordinators, and school administrators who have experience in implementing digital transformation in schools (Razak et al., 2018). In addition, a comprehensive literature review is conducted by examining established digital maturity models and international frameworks such as those developed by UNESCO and the OECD. These sources provide validated indicators and conceptual foundations for defining digital transformation maturity levels in secondary education.

The acquired knowledge is then transformed into a structured knowledge representation in the form of production rules (Collins, 2017). These rules are expressed as IF-THEN statements that define relationships between input conditions and output conclusions. For example, IF ICT infrastructure is high AND teacher digital competence is high, THEN the digital maturity level is classified as advanced. This rule-based structure allows expert knowledge to be formalized into a computational format that can be processed by the system.

The inference mechanism used in this expert system is Forward Chaining (Ogheneovo & Nlerum, 2020). This method begins with known facts obtained from user inputs, such as questionnaire responses from schools. The system then applies relevant rules sequentially to derive new facts until a

final conclusion is reached. In this case, the conclusion represents the digital transformation maturity level of the school, ensuring that the reasoning process is transparent and traceable.

The system is developed using appropriate programming tools such as Python or a web-based programming language like PHP, depending on the implementation environment (Laurent et al., 2001). The system architecture consists of three main components: the user interface, which allows users to input data; the knowledge base, which stores all IF-THEN rules; and the inference engine, which processes input data using Forward Chaining to generate conclusions.

Data collection is conducted using structured questionnaires distributed to secondary schools (Saidi & Siew, 2019). The questionnaire is designed based on key indicators of digital transformation maturity, including ICT infrastructure availability, teacher digital literacy, digital learning adoption, and school policy support for digital transformation. These indicators are measured to provide a comprehensive understanding of each school's level of digital readiness.

Finally, system testing is performed to evaluate both the accuracy and functionality of the expert system. Accuracy testing is conducted by comparing the system's output with expert evaluations to determine the level of consistency and reliability. In addition, black-box testing is used to ensure that all system functions operate correctly based on input-output behavior without analyzing the internal program structure. Through these testing methods, the system's performance in identifying digital transformation maturity levels can be validated effectively.

### 3. Results and Discussion

#### 3.1 System Implementation

The expert system for identifying digital transformation maturity levels is implemented as a user-friendly application designed to assist school administrators and ICT coordinators in evaluating their institution's digital readiness. The system is built with a structured interface consisting of several main components, including an input form page and a results display page.

The input form interface is designed to collect data related to key indicators of digital transformation in secondary schools (West, 2012). Users are required to fill in structured questionnaire items that represent various aspects of digital maturity, such as ICT infrastructure availability, teacher digital literacy, digital learning implementation, curriculum integration of technology, and school policy support. Each indicator is typically measured using a predefined scale (for example, Likert scale or categorical values such as low, medium, and high), which allows the system to convert user responses into factual inputs for the inference engine.

Once the data is submitted, the system processes the input through the knowledge base and inference engine (Daly et al., 2002). The Forward Chaining mechanism then evaluates the input facts against the predefined IF-THEN rules stored in the system. Based on this reasoning process, the system generates a classification result that represents the school's digital transformation maturity level.

The results page displays the output of the system in a clear and structured format. It shows the final maturity classification, such as initial, developing, established, or advanced, depending on the combination of input indicators. In addition to the final result, the system may also provide an explanation or reasoning path that shows which rules were activated during the inference process. This feature increases transparency and helps users understand how the conclusion was reached.

Overall, the system implementation demonstrates that the expert system is capable of processing structured school data and transforming it into meaningful information regarding digital transformation maturity. The interface design ensures ease of use, while the inference mechanism provides consistent and rule-based decision support for evaluating school readiness in digital transformation.

#### 3.2 Knowledge Base Output

The knowledge base is a fundamental component of the expert system, as it stores domain knowledge in the form of structured rules that represent expert reasoning regarding digital transformation maturity in secondary schools. This knowledge base is constructed from expert

interviews and literature on digital maturity frameworks, which are then translated into IF-THEN production rules. These rules serve as the foundation for the system's decision-making process.

The rules used in the system are designed to reflect the relationships between key indicators of digital transformation and the resulting maturity levels. Each rule combines multiple conditions related to ICT infrastructure, teacher competence, digital learning implementation, and institutional support (Anderson, 2010). For example, one of the rules in the system can be expressed as: IF ICT infrastructure is high AND teacher digital literacy is high AND digital learning adoption is high THEN the school's digital maturity level is classified as advanced. Another rule may state: IF ICT infrastructure is medium AND teacher competence is moderate AND digital learning adoption is partial THEN the maturity level is categorized as developing. These rules allow the system to differentiate between various levels of digital readiness based on combinations of input conditions.

The logic behind these rules is based on expert reasoning and established digital maturity frameworks, where each indicator contributes collectively to the overall maturity level of a school. The use of IF-THEN rules enables the system to simulate human expert decision-making in a structured and consistent manner (Baster et al., 2013). Each rule represents a specific pattern of conditions that, when satisfied, leads to a defined conclusion. This rule-based structure ensures that the system does not rely on subjective judgment but instead applies standardized logic to every evaluation.

Furthermore, the knowledge base is designed to support scalability and flexibility. New rules can be added or existing rules modified as digital transformation practices evolve over time (Westerman et al., 2014). This ensures that the system remains relevant and adaptable to changes in educational technology and policy. Through this structured knowledge representation, the expert system is able to provide transparent, consistent, and explainable outputs regarding the digital transformation maturity level of secondary schools.

### 3.3 Inference Process (Forward Chaining)

The inference process in this expert system is carried out using the Forward Chaining method, which is a data-driven reasoning technique that starts from known facts and moves forward through a set of predefined rules until a final conclusion is reached. In the context of this study, the known facts are obtained from the input provided by users through the system questionnaire, which includes indicators such as ICT infrastructure, teacher digital literacy, digital learning adoption, curriculum integration, and school policy support.

The reasoning process begins when the user submits all required input data (Karafili et al., 2018). These inputs are then converted into factual statements that are recognized by the system. For example, a school may be identified as having high ICT infrastructure, moderate teacher digital literacy, and high digital learning adoption. These facts are stored in the working memory of the system and serve as the starting point for the inference process.

Next, the system performs rule matching by comparing the input facts with the conditions defined in the knowledge base. When a rule's conditions are fully satisfied by the available facts, that rule becomes activated. For instance, if a rule states that IF ICT infrastructure is high AND teacher digital literacy is high AND digital learning adoption is high THEN the maturity level is advanced, and all these conditions are met by the input data, then the rule is triggered.

Once a rule is activated, the system generates a new fact, which in this case is the conclusion regarding the school's digital transformation maturity level (Ifenthaler & Egloffstein, 2020). This newly derived fact is then added to the working memory, and the process continues until no further rules can be activated. Through this iterative process, the system gradually builds logical conclusions based on the available data.

Finally, the inference process results in a definitive output classification of the school's digital transformation maturity level, such as initial, developing, established, or advanced. This step-by-step reasoning process ensures that the decision-making mechanism is transparent, traceable, and consistent with expert knowledge, allowing users to understand how the final conclusion was derived from the initial input facts.

### 3.4 Output Results

The output of the expert system is presented in the form of a structured classification that represents the digital transformation maturity level of secondary schools. After the inference process is completed through the Forward Chaining mechanism, the system generates a final conclusion based on the combination of input facts and activated rules. This output is designed to provide clear, interpretable, and actionable information for school stakeholders, particularly administrators and ICT coordinators.

The maturity classification is divided into four hierarchical levels (Cavalcante de Souza Feitosa et al., 2021). The first level, referred to as Level 1: Initial, describes schools that are in the early stage of digital transformation. At this stage, the use of digital technology is still minimal, infrastructure is limited, and digital integration in teaching and administrative processes is not yet well established. Schools at this level generally require significant improvements in both technological resources and human resource competencies.

The second level, Level 2: Developing, represents schools that have begun to adopt digital technologies but are still in the process of integration (Petko et al., 2015). In this stage, some digital tools are used in learning and administration; however, their implementation is not yet consistent or fully optimized. Teacher digital literacy may vary, and institutional support for digital transformation is still in development.

The third level, Level 3: Established, indicates that the school has successfully integrated digital technologies into most aspects of its operations (Ilomäki & Lakkala, 2018). At this level, digital learning platforms, administrative systems, and ICT infrastructure are widely utilized. Teachers demonstrate a relatively high level of digital competence, and school policies actively support digital transformation initiatives.

The fourth level, Level 4: Advanced, represents schools that have fully integrated digital transformation into their academic and administrative systems (Rodríguez-Abitia & Bribiesca-Correa, 2021). These schools demonstrate strong ICT infrastructure, high digital literacy among educators, and a well-structured digital ecosystem that supports continuous innovation. Digital technologies are embedded into teaching, learning, assessment, and governance processes in a sustainable and optimized manner.

Overall, this classification output allows stakeholders to clearly understand the current position of their institution in the digital transformation journey. It also provides a basis for strategic planning and continuous improvement in order to progress toward higher levels of digital maturity.

### **3.5 Interpretation of Results**

The results generated by the expert system provide a structured representation of a secondary school's position within the digital transformation maturity continuum. The interpretation of these results is essential to understand not only the classification outcome but also the implications behind each maturity level and the contributing factors that influence it.

When a school is classified at Level 1: Initial, the interpretation indicates that the institution is still in the early stage of digital transformation. This suggests that digital technologies are either minimally used or not yet systematically integrated into teaching and administrative processes. In this condition, schools typically face limitations in ICT infrastructure, lack of teacher readiness in digital competencies, and absence of clear institutional policies supporting digital initiatives. Therefore, the result implies an urgent need for foundational improvements, particularly in infrastructure development and capacity building for educators.

For schools categorized as Level 2: Developing, the interpretation shows that digital transformation has begun but remains inconsistent (Kopp et al., 2019). Schools at this stage have initiated the use of digital tools; however, implementation is often partial and dependent on specific individuals or programs. This indicates that while progress has been made, there is still a lack of standardization and integration across the institution. The system's output at this level highlights the need for stronger coordination, improved teacher training, and more consistent policy enforcement to ensure sustainable digital adoption.

In the case of Level 3: Established, the results reflect that the school has achieved a relatively stable and integrated level of digital transformation (Rodríguez-Abitia & Bribiesca-Correa, 2021). Digital tools are widely used in both learning and administrative functions, and teachers generally possess adequate digital competencies. The interpretation of this result suggests that the school has successfully embedded digital technologies into its operational framework. However, continuous improvement is still necessary to optimize usage, enhance innovation, and ensure long-term sustainability.

Meanwhile, Level 4: Advanced represents the highest maturity stage, where digital transformation is fully integrated into all aspects of school operations (Begicevic Redjep et al., 2021). Schools at this level demonstrate strong ICT infrastructure, high levels of digital literacy among educators, and well-developed digital governance systems. The interpretation of this result indicates that the institution is not only utilizing digital technologies effectively but also continuously innovating and adapting to emerging technological trends. Such schools can be considered as benchmarks for best practices in digital education transformation.

Overall, the interpretation of results provides meaningful insights for decision-makers by translating system outputs into actionable understanding. It enables schools to identify their current position, recognize gaps in their digital transformation journey, and develop targeted strategies for improvement.

### 3.6 Comparison with Expert Evaluation

The comparison between the results generated by the expert system and the evaluations conducted by human experts is an important stage in validating the performance and reliability of the proposed system. This process aims to determine the extent to which the Forward Chaining-based expert system can replicate or approximate the decision-making patterns of domain experts in assessing digital transformation maturity levels in secondary schools.

In this study, expert evaluation is carried out by education professionals, such as ICT coordinators, school administrators, and experts in educational technology, who assess schools based on the same set of indicators used in the system (Solar et al., 2013). These experts provide maturity classifications based on their experience and professional judgment, which serve as a benchmark for comparison with the system-generated outputs.

The comparison results generally indicate a high level of consistency between the expert system and human expert assessments. In many cases, the system is able to correctly classify schools into the same maturity levels as determined by experts, particularly when the input data is complete and clearly reflects the defined indicators. This suggests that the rule-based structure and Forward Chaining inference mechanism are effective in capturing expert reasoning in a systematic and computational form.

However, some differences may occur in borderline cases where the characteristics of a school do not clearly fall into a single maturity category. In such situations, human experts may consider contextual or qualitative factors that are not fully represented in the system's rule base. These discrepancies highlight one of the limitations of rule-based systems, which rely heavily on predefined rules and may not fully accommodate complex or ambiguous real-world conditions.

Despite these minor differences, the overall comparison demonstrates that the expert system provides a reliable approximation of expert judgment (Caley et al., 2014). The system offers the advantage of consistency, repeatability, and transparency in decision-making, whereas human evaluation may vary depending on individual interpretation. Therefore, the integration of expert system results with expert validation strengthens the credibility of the proposed approach and confirms its usefulness as a decision support tool for assessing digital transformation maturity in secondary schools.

### 3.7 Strengths and Limitations of Forward Chaining

The use of the Forward Chaining method in the expert system provides several significant strengths, particularly in terms of transparency and structured reasoning. One of the main advantages of Forward Chaining is its ability to produce clear and traceable decision-making processes (Irfan et al.,

2018). Since the reasoning begins with known input facts and progresses step-by-step through rule activation, every conclusion generated by the system can be explained based on specific conditions. This makes the decision-making process highly transparent, allowing users to understand how a particular digital transformation maturity level is reached. In the context of secondary school evaluation, this transparency is particularly important because stakeholders such as school administrators and policymakers require clear justification for each assessment result.

Another strength of Forward Chaining is its systematic and logical approach to problem-solving. The method ensures that all relevant rules are evaluated based on available input data, reducing the possibility of arbitrary or inconsistent decisions. This leads to more standardized and repeatable outcomes when assessing similar cases. Additionally, Forward Chaining is well-suited for applications where data is gradually collected and used to infer conclusions, such as questionnaire-based evaluation systems used in this study.

Despite these advantages, the Forward Chaining approach also has certain limitations (Mzori, 2015). One of the main limitations is its strong dependence on the completeness and accuracy of the rule base. The system can only produce reliable results if all relevant conditions and scenarios have been properly represented in the IF-THEN rules. If certain conditions are missing or not adequately defined, the system may generate incomplete or less accurate conclusions. This means that the quality of the expert system is highly influenced by the quality of knowledge acquisition from experts.

Furthermore, Forward Chaining may become less efficient when dealing with a very large number of rules, as the inference process may require extensive rule matching. It is also less flexible in handling ambiguous or uncertain data compared to probabilistic or machine learning-based approaches. However, in the context of this research, where interpretability and rule-based reasoning are prioritized, Forward Chaining remains a suitable and effective method for assessing digital transformation maturity in secondary schools.

#### 4. Conclusion

The expert system developed in this study successfully identifies the digital transformation maturity level of secondary schools based on structured indicators and rule-based reasoning. The implementation of the Forward Chaining inference mechanism proves effective in deriving conclusions from user input and predefined IF-THEN rules, ensuring that the decision-making process is systematic, transparent, and consistent with expert knowledge. The system is able to assist schools in evaluating their digital readiness in a more structured and objective manner compared to traditional manual assessments, thereby reducing subjectivity in evaluation. In addition, the system provides valuable decision support for school management and policymakers in planning and improving digital transformation strategies. For future development, the system can be enhanced by integrating hybrid approaches with machine learning techniques to improve adaptability, expanding its application to primary and higher education levels, and incorporating real-time data analytics to support more dynamic and continuous assessment of digital transformation maturity.

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