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Analysis Of Dominant Risks Affecting Time Performance Based On The Work Breakdown Structure (WBS) Of Deep Soil Mixing (DSM) Works

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Abstract

Deep Soil Mixing (DSM) work is a soil improvement method widely used in construction projects on soft soil. Although effective in improving the geotechnical characteristics of the soil, DSM implementation still faces various risks that have the potential to cause project delays. This study aims to identify and analyze the dominant risks that affect the time performance of DSM work based on the Work Breakdown Structure (WBS) approach. The study used a mixed method, namely a qualitative approach for the preparation and validation of the WBS through the Delphi method involving five experienced experts in the field of Soil Improvement, and a quantitative approach for risk analysis using the Severity Index (SI). The results of the study produced a WBS structure for DSM work up to Level 6 consisting of work packages, implementation methods, activities, and resources. Based on the risk mapping in the WBS, 51 risk variables were identified that have the potential to affect the time performance of the project. The risk analysis showed that there were 12 dominant risks with a high risk category. The main risks include Unconfined Compressive Strength (UCS) results that do not meet specifications, low labor quality, curing wait time, variability in soil conditions, working platform instability, delays in material delivery, and equipment damage. The results of the study show that the implementation of WBS-based risk management can help systematically identify risks and support improved time performance in DSM work.

Keywords: ***Risk Analysis, Work Breakdown Structure (WBS), Deep Soil Mixing (DSM), and Time Performance.***

INTRODUCTION

Construction project development consists of a series of interrelated construction activities that have specific objectives and are carried out within a defined timeframe, where each project has unique conditions that influence its implementation process (Ervianto, 2005). The construction industry faces significant challenges in the form of uncertainties that may generate various risks at every stage of project execution. One aspect that frequently encounters obstacles is subsurface soil conditions. To address these issues, ground improvement technologies such as Deep Soil Mixing (DSM) have been widely implemented, particularly in infrastructure projects located in areas with weak soil conditions.

The DSM method involves the in-situ mixing of soil with binding agents such as cement or lime to improve soil shear strength and stability (Terashi & Tanaka, 1981). This technology is recognized as an effective solution for increasing soil bearing capacity, reducing settlement, and enhancing slope stability (Bruce, 2000).

As one of the ground improvement methods, Deep Soil Mixing (DSM) is a critical early-stage activity in construction projects because it determines site suitability for foundation and superstructure works. Delays at this stage may create a domino effect on subsequent activities and potentially lead to overall project delays (Ajayi et al., 2022).

Despite its numerous technical advantages, DSM implementation still faces several challenges in practice. The success of DSM depends on various factors, including the type and condition of the native soil, the quality and proportion of binding materials, mixing techniques, and environmental conditions during execution (Chu et al., 2009). Therefore, a risk analysis related to the schedule performance of DSM projects is required. In this study, the Work Breakdown Structure (WBS) standard is utilized as a tool to identify and map risks occurring during DSM operations. WBS plays an important role in construction projects by providing a consistent framework for all project stakeholders. Defining project scope according to project requirements is essential for achieving project success (Project Management Institute, 2017).

Literature Review

Deep Soil Mixing (DSM)

Deep Soil Mixing (DSM) is a ground improvement method that strengthens soft soil by mixing it in situ with binding agents (typically cement or lime) using specialized equipment, thereby forming stronger and more stable soil columns or blocks (Terashi, 2003). According to Kitazume and Terashi (2013), DSM is one of the most effective ground improvement techniques for water-saturated soft soils because it increases shear strength, reduces compressibility, and improves the overall stability of embankments.

Bruce (2001) states that DSM is an effective ground improvement method because it enhances the geotechnical properties of soft soils through the homogeneous mechanical mixing of stabilization materials. Similarly, Terashi (2003) explains that DSM can significantly alter soil characteristics by creating stabilized soil columns with greater strength and bearing capacity than the original soil conditions.

Porbaha (1998) identified DSM as an innovative technology that was considered revolutionary because it could improve soil conditions more rapidly than conventional methods such as preloading or soil replacement. According to Kitazume and Terashi (2013), DSM has developed rapidly since the 1980s due to the increasing demand for infrastructure construction on soft soils. Applications of DSM include:

1. Foundations for low- to medium-rise buildings.
2. Foundations for embankments and river revetments.
3. Soil stabilization for road embankments and dikes.
4. Retaining walls.
5. Settlement reduction for building foundations.
6. Construction of cut-off walls to control seepage.
7. Liquefaction risk mitigation in saturated sandy soils.

Work Breakdown Structure (WBS)

A Work Breakdown Structure (WBS) is a hierarchical decomposition of project activities into smaller work elements that describe construction methods, project cost allocation, and data presentation, enabling more effective planning, reporting, and control (Kerzner, 2006). The efficiency of WBS implementation significantly influences project success because it serves as the primary foundation for project planning (Devi & Reddy, 2012).

According to Haugan (2002), a WBS is developed to ensure that all project work is comprehensively and accurately defined. At the highest level (Level 1), the WBS represents the entire project, which is then decomposed into smaller elements at Level 2 based on major deliverables. Several approaches may be used to determine WBS levels, including major deliverable-based and project life cycle-based approaches. The lowest level of a WBS is the work package, which represents a specific work component assigned to an individual or organization for execution (Ibrahim et al., 2009).

To date, no standardized Work Breakdown Structure (WBS) has been specifically developed for Deep Soil Mixing (DSM) works. Therefore, this study also aims to establish a standardized DSM WBS to support more systematic and adaptive project implementation.

Risk Analysis

According to PMI (2017), project risk analysis can be conducted using either quantitative or qualitative approaches. This study employs qualitative risk analysis, which is the process of prioritizing project risks for further action by assessing their probability of occurrence, impact, and other relevant characteristics. The primary benefit of this process is to focus attention and resources on high-priority risks.

Risk analysis serves as one of the study variables and is considered the dependent variable influenced by other variables, including the impact and frequency of risk occurrences, as well as risk response measures.

The qualitative risk analysis process is based on questionnaire data using frequency and impact scales. The risk value for each variable is obtained by multiplying the frequency score by the impact score. Based on the PMBOK Guide Fifth Edition, the levels of probability (frequency) and severity (impact) of risk variables can be represented using a Probability and Impact Matrix, as shown in Table 1.

Table 1. Probability and Impact Matrix

Probability	***Threats***				
0,90	0,05	0,09	0,18	0,36	0,72
0,70	0,04	0,07	0,14	0,28	0,56
0,50	0,03	0,05	0,10	0,20	0,40
0,30	0,02	0,03	0,06	0,12	0,24
0,10	0,01	0,01	0,02	0,04	0,08
	0,05 Very Low	**0,10 Low**	**0,20 Moderate**	**0,40 High**	**0,80 Very High**

(Source: PMBOK 6th Edition, 2017)

RESEARCH METHODS

This research combines a qualitative approach to developing the WBS structure and a quantitative approach to analyzing risk severity versus time. The research process is divided into three main stages. The first stage is the initial development of the DSM work WBS component structure (Levels 1 to 6) based on a literature review and project operational technical documents.

The second stage involves an Expert Validation process using the Delphi Round Method. This process involves five experts (with at least 10 years of experience in Soil Improvement/Deep Soil Mixing) to revise and agree on the WBS decomposition down to Levels 5 (Activities) and 6 (Resources). The third stage involves the distribution of a risk assessment questionnaire, identified based on the work package level, implementation method, activity level, and resource level in the validated WBS, to measure the probability and impact of the risk versus time.

The risk index value is obtained by multiplying the probability and impact scores (Index = Probability x Impact). The index value is based on Table 1. Probability and Impact Matrix, then classified into the risk matrix: Low Risk (0.01–0.05), Medium Risk (0.06–0.24), and High/Dominant Risk (0.28–0.72).

RESULTS AND DISCUSSION

DSM Work WBS Standard

Based on a series of data collection, literature studies, analysis of project documents such as method statements from several DSM projects at PT. XYZ, and initial and final expert validation, this study found that the most appropriate standard WBS format for Deep Soil Mixing (DSM) work is one that is structured hierarchically from the project level to the resource level, and developed based on the sequence of work implementation in the field. This WBS format not only contains a general division of work but also outlines the work stages in detail, down to the implementation activities and the resources required for each activity. Thus, the resulting WBS is operational, applicable, and can be used as a standard reference in DSM work implementation.

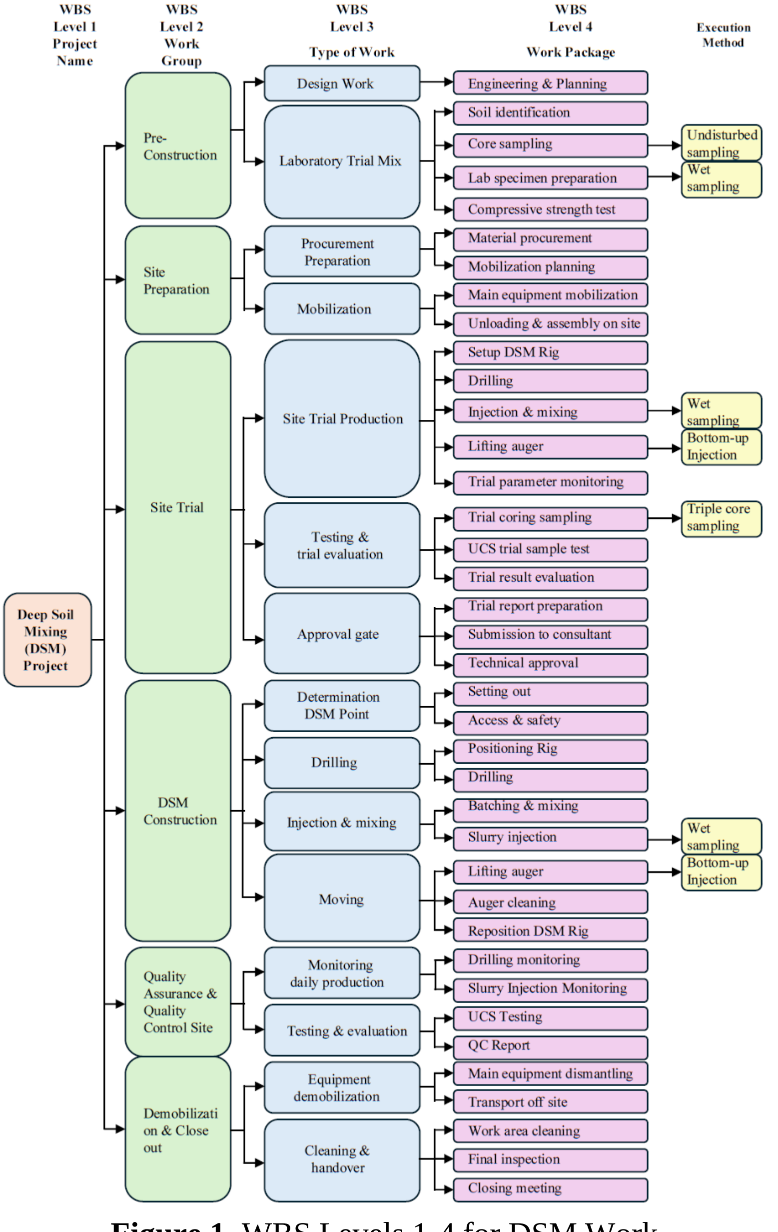

Figure 1. WBS Levels 1-4 for DSM Work
Source: Author's Processed Results (2026)

The following is an example of a DSM work WBS that has been validated by experts up to Level 5 (Activities) and Level 6 (Resources):
Level 2 (Work Group) = Site Trial
Level 3 (Work Package) = Laboratory Trial Mix

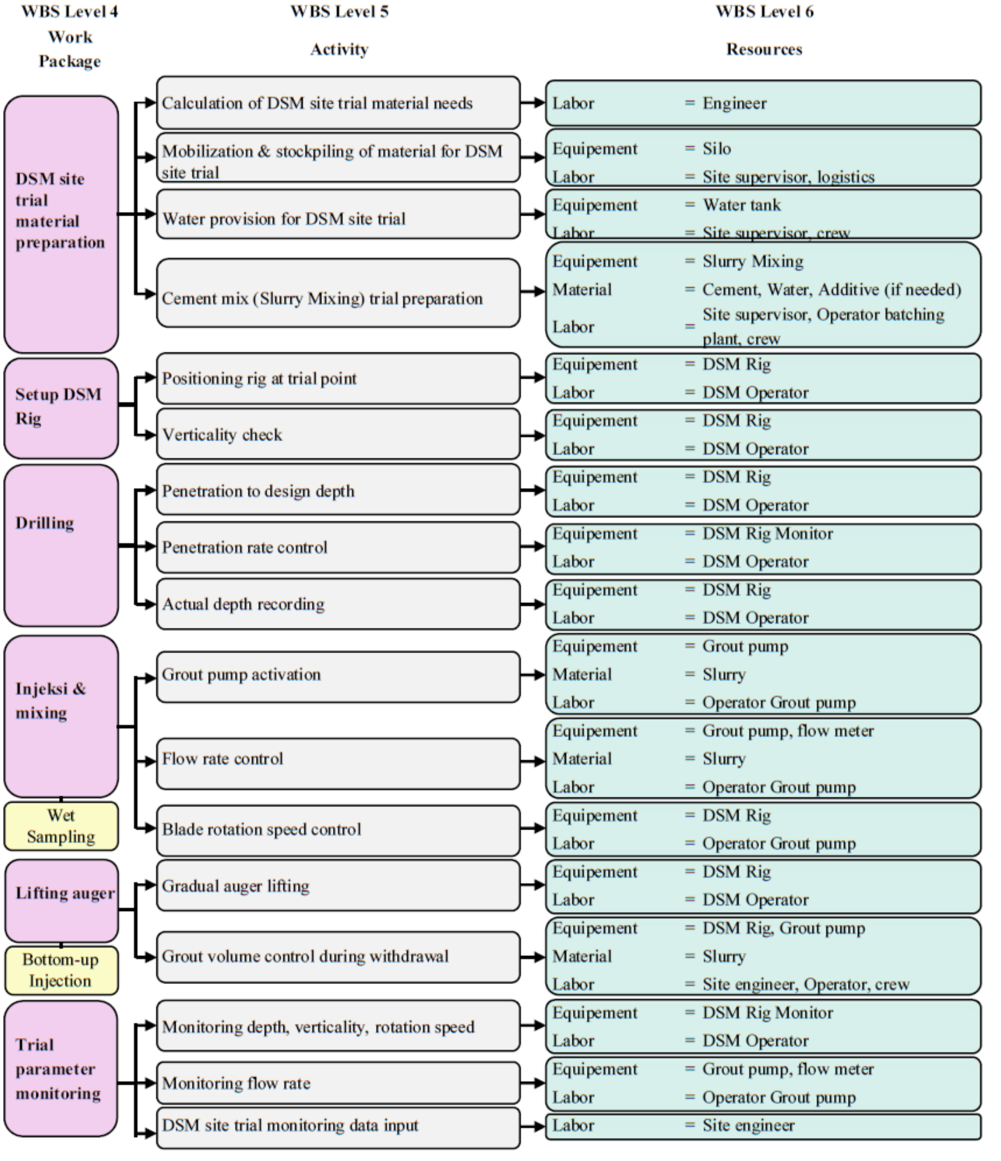

Figure 2. Example of a WBS up to Levels 5-6 for DSM Work
Source: Author's Processed Results (2026)

Identifying Time Performance-Related Risks Based on the WBS for DSM Work

Based on the Work Breakdown Structure (WBS) validated by experts using the Delphi method in the previous stage, the next step was to identify risks at levels 4-6 of the WBS. Through this approach, a thorough mapping of potential risks was conducted based on the WBS elements for the Deep Soil Mixing (DSM) work. From this work decomposition-based mapping, 51 risks were identified that could potentially impact the project's time performance.

Table 4. Summary of Time Performance-Related Risk Identification Results

WBS Level	Risks Affecting Project Performance
Level 4 – Work Package	14 Risks
Execution Method	2 Risks
Level 5 – Activity	20 Risks
Level 6 – Material Resources	5 Risks
Level 6 – Equipment Resources	5 Risks
Level 6 – Labor Resources	4 Risks
Total	**51 Risks**

Source: Author's Processed Results (2026)

Risk Collection and Analysis – Respondent Risk Questionnaire

Pilot Survey

The risk analysis data collection in this study began with a pilot survey to test respondents' understanding of the research indicators. This pilot survey involved 10 (ten) respondents with at least 3-5 years of work experience in the field of Deep Soil Mixing (DSM)/Soil Improvement and with at least a bachelor's degree. The analysis results showed that all variables were well understood by the respondents, thus declaring the questionnaire suitable for use in the next data collection stage.

Respondent Questionnaire Survey

Data collection for the analysis of relationships between variables was conducted to answer the research question regarding the dominant risks of DSM work. Data was collected through an online questionnaire that included respondents' demographic information and the research questions. Of the 60 questionnaires distributed, 51 were completed completely and validly, resulting in a response rate of 85%.

The study respondents came from contractor and consulting companies, with a minimum of 3-5 years of work experience in Deep Soil Mixing (DSM) or Soil Improvement, and a minimum of a bachelor's degree. The respondent data was used as the basis for analyzing the dominant risks of DSM work.

Homogeneity Test

This study involved 51 research variables measured by a data sample of 51 respondents. A homogeneity test was conducted to ensure uniformity of data characteristics by grouping respondents based on their institution, education level, and work experience. Data processing was performed statistically using SPSS software with a significance level of 0.05. Data were considered homogeneous if the significance value was greater than 0.05.

Homogeneity Test by Institution

A homogeneity test was conducted to determine whether there were differences in respondents' perceptions of the questionnaire answers based on the institution where they worked.

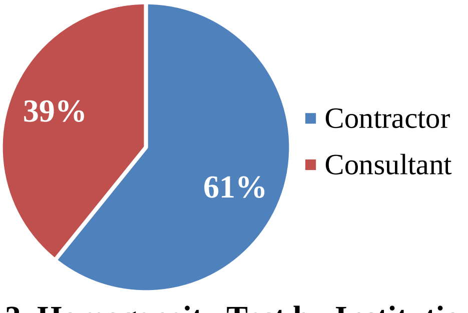

Figure 3. Homogeneity Test by Institution

The SPSS analysis results above show that all indicators have an Asymp. sig. > 0.05, with the smallest value being 0.052. This indicates that there are no differences in perceptions based on agency group. All indicators confirm H0, meaning there are no differences in respondents' perceptions at each institution where they work.

Homogeneity Test Based on Work Experience

The homogeneity test was conducted to determine whether there are differences in respondents' perceptions of the questionnaire answers based on length of work experience.

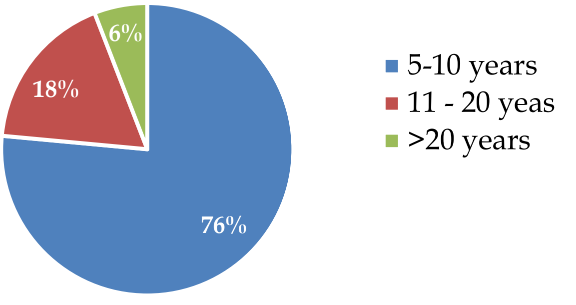

Figure 4. Homogeneity Test Based on Work Experience

The SPSS analysis results above show that all indicators have an Asymp.sig > 0.05, with the smallest value being 0.065. This indicates that there is no difference in perception based on work experience. All indicators confirm H0, meaning there is no difference in respondents' perceptions at each level of work experience.

Homogeneity Test by Education

The homogeneity test was conducted to determine whether there are differences in respondents' perceptions of the questionnaire answers based on their highest level of education.

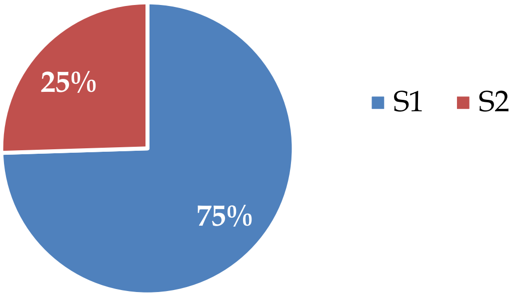

Figure 5. Homogeneity Test by Education

The SPSS analysis results above show that all indicators have an Asymp.sig > 0.05, with the smallest value being 0.052. This indicates that there are no differences in perceptions based on education level. All indicators confirm H0, meaning there are no differences in respondents' perceptions at each education level.

Data Adequacy Test

A data adequacy test was conducted to determine whether the collected data was sufficient for further calculations. Based on the calculation results, the N' value ≤ N = 22.5 ≤ 51. Therefore, it can be concluded that the amount of data used was sufficient.

Validity and Reliability Test

A validity test is conducted to assess the accuracy of a measurement instrument in carrying out its function, while a reliability test aims to determine the level of consistency and reliability of the measurement instrument. Validity and reliability tests in this study were conducted using SPSS software.

The results of the analysis using SPSS show that to test whether the data is valid or not is by looking at the Corrected Item-Total Correlation value > r table for dof = 49, namely 0.276, it was found that several variables were invalid, but in the homogeneity test, the variables were included in the respondent response population. The reliability test conducted obtained that all variable data fell into the range of 0.8 < x < 1.0 so that all data were very reliable.

Qualitative Risk Analysis

The risk analysis in this study was conducted using a qualitative approach, applying the Severity Index (SI) method to process data obtained from the respondent questionnaire. The mean score for the frequency and impact variables was first calculated separately for all respondents, and then multiplied to obtain the final risk score.

Table 5. Risk Rating

Variable	Average Frequency	Average Impact	Risk Value	Risk Rating
X1	0.48	0.38	0.18	30
X2	0.69	0.53	0.37	7
X3	0.48	0.37	0.17	38
X4	0.50	0.36	0.18	33
X5	0.53	0.43	0.22	13
X6	0.57	0.35	0.20	22
X7	0.59	0.37	0.21	16
X8	0.51	0.35	0.18	35
X9	0.50	0.36	0.18	36
X10	0.72	0.54	0.38	5
X11	0.68	0.57	0.38	4
X12	0.52	0.42	0.22	14
X13	0.65	0.51	0.34	12
X14	0.49	0.31	0.15	48
X15	0.54	0.32	0.17	42
X16	0.48	0.32	0.15	49
X17	0.55	0.37	0.20	20
X18	0.55	0.37	0.20	21
X19	0.49	0.32	0.16	47
X20	0.73	0.53	0.39	3
X21	0.52	0.32	0.16	45
X22	0.71	0.48	0.34	11
X23	0.56	0.34	0.19	28
X24	0.74	0.58	0.42	1
X25	0.56	0.32	0.18	31
X26	0.49	0.34	0.17	43
X27	0.52	0.38	0.20	23
X28	0.53	0.34	0.18	34
X29	0.52	0.37	0.19	27
X30	0.53	0.37	0.20	25
X31	0.56	0.37	0.21	19
X32	0.54	0.39	0.21	18
X33	0.52	0.34	0.18	32
X34	0.56	0.39	0.22	15
X35	0.52	0.38	0.20	24
X36	0.51	0.33	0.17	44
X37	0.50	0.38	0.19	29
X38	0.50	0.34	0.17	40
X39	0.72	0.53	0.38	6
X40	0.49	0.30	0.15	50
X41	0.54	0.36	0.19	26
X42	0.42	0.41	0.17	39
X43	0.48	0.36	0.17	41
X44	0.70	0.52	0.36	8
X45	0.50	0.32	0.16	46

Variable	Average Frequency	Average Impact	Risk Value	Risk Rating
X46	0.69	0.52	0.36	9
X47	0.53	0.33	0.18	37
X48	0.72	0.56	0.40	2
X49	0.68	0.53	0.36	10
X50	0.55	0.38	0.21	17
X51	0.30	0.25	0.07	51

Source: Author's Processed Results (2026)

The risk ranking in this study was selected based on the risk level, with a high risk category with a nominal value above 0.280, as shown in the table above. Under these conditions, 12 factors or variables with the greatest risk (≥0.280) were selected. This risk level was obtained by multiplying the average frequency and the average impact assessed by 51 respondents. The results of multiplying the frequency and impact of the 51 respondents yielded the following dominant risks to time performance:

Table 6. Dominant DSM Job Risks

Variable	Risk	Risk Ranking
X24	UCS test results do not meet the required specifications	1
X48	Low workforce quality	2
X20	Curing waiting period (14–28 days) causes delays in decision-making	3
X11	Unexpected variability in soil conditions	4
X10	Instability of the working platform causing equipment tilting	5
X39	Delay in material delivery	6
X2	Discrepancy between design assumptions and actual soil conditions in the field	7
X44	Equipment damage or failure	8
X46	Equipment capacity unsuitable for field conditions	9
X49	Insufficiently trained DSM operators	10
X22	Delay in equipment mobilization to the site	11
X13	Extreme weather conditions (heavy rain, flooding)	12

Source: Author's Processed Results (2026)

The 12 selected variables are high-level risk variables (≥0.280) and, during field observations, were frequently encountered during construction work. Therefore, these variables are quite dominant and influence construction progress.

Discussion

Based on the results of the qualitative risk analysis, 12 dominant risks were identified that affect the performance of the Deep Soil Mixing (DSM) project. These risks are dominated by aspects of work quality, geotechnical conditions, equipment, logistics, and human resources. This finding aligns with the PMI (2021) opinion that construction project delays are generally influenced by technical factors, resources, and project environmental conditions.

The risk with the highest level of dominance is the Unconfined Compressive Strength (UCS) result that does not meet specifications (X24). According to Masaki Kitazume and Terashi (2013), the quality of DSM columns is influenced by soil characteristics, binder type and content, and mixing parameters during construction. If the UCS value does not meet design requirements, retesting or corrective work is required, potentially delaying the project. Therefore, conducting trial mixes, laboratory testing, equipment calibration, and monitoring production parameters are important mitigation measures.

The risk of a 14–28-day curing lead time (X20) also contributes to delays in project decision-making because UCS test results can only be evaluated after the curing process is complete. According to Bruce (2012), quality verification in ground improvement projects often causes delays due to the time lag between implementation and evaluation. Mitigation measures include conducting trial columns, testing early-age compressive strength, and developing a schedule that takes the curing period into account.

Variability in ground conditions (X11) and design discrepancies with actual field conditions (X2) indicate that geotechnical uncertainty is a major risk factor in DSM projects. According to Terzaghi, Peck, and Mesri (1996), subsurface conditions are one of the greatest sources of uncertainty in geotechnical projects. Therefore, adequate soil investigations, trial columns, and adjustments to construction parameters based on field conditions are necessary to minimize these risks.

The risks of working platform instability (X10), low-quality labor (X48), poorly trained operators (X49), equipment damage (X44), and inadequate equipment capacity (X46) have the potential to reduce productivity and the quality of work. The Federation of Piling Specialists (2017) emphasized the importance of a stable working platform to ensure the safety and performance of heavy equipment. Meanwhile, Hinze (2011) stated that workforce competence directly impacts the productivity and quality of construction work. Therefore, operator training, implementation of SOPs, routine inspections, and preventive maintenance programs need to be consistently implemented.

Furthermore, delays in material delivery (X39), delays in equipment mobilization (X22), and extreme weather (X13) can disrupt the smooth running of work. Kerzner (2022) explained that logistical issues are one of the main causes of construction project delays. Mitigation measures include sound logistics planning, providing buffer stock, coordinating mobilization from the early stages of the project, and adjusting schedules based on weather conditions.

Overall, the research results indicate that the dominant risks in DSM projects stem from soil stabilization quality, geotechnical uncertainty, equipment readiness, and human resource competency. Therefore, implementing integrated risk management from the soil investigation stage, design, construction, and quality control is necessary to improve project time performance and the success of DSM projects.

CONCLUSIONS

Based on the results of risk identification and analysis for Deep Soil Mixing (DSM) work using the Work Breakdown Structure (WBS) approach, it can be concluded that a WBS structure compiled up to Level 6 can provide a systematic basis for identifying risk sources at each work stage. Through expert validation using the Delphi method, a WBS structure was obtained consisting of work packages, implementation methods, activities, and resources involved in the DSM implementation.

The risk mapping results based on the WBS yielded 51 risk variables that could potentially impact project time performance. Based on qualitative risk analysis using the Severity Index (SI) method, 12 dominant risks were identified, categorized as high-risk. The risks with the greatest impact on time performance were unconfined compressive strength (UCS) test results that did not meet specifications, low labor quality, curing wait times that caused delays in decision-making, unpredictable variability in soil conditions, and working platform instability that could disrupt equipment operations.

To control these dominant risks, mitigation strategies appropriate to the identified risk sources are required. Based on the discussion, mitigation efforts include improving quality control of DSM work, conducting more comprehensive soil condition investigations and verifications, improving workforce and operator competency, implementing preventative equipment maintenance, and strengthening project logistics and scheduling planning.

The research findings indicate that delays in DSM work are not only influenced by technical implementation factors, but also by aspects of work quality, geotechnical conditions, equipment readiness, workforce competency, and smooth project logistics. The implementation of structured risk management based on the WBS is expected to assist contractors and project stakeholders in identifying risks early, prioritizing control measures, and minimizing potential delays, thereby achieving optimal Deep Soil Mixing work schedules.

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