Intelligent Framework for Monitoring Sustainable Development Goals within Project Portfolios and Programs*

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Abstract

The paper aims to develop an approach for monitoring the execution of projects' portfolios and programs to achieve the Sustainable Development Goals (SDGs). The article presents an integrated model that combines the Work Breakdown Structure (WBS) with the Sustainable Development Goals Indicator System (SGBS), enabling effective project monitoring, control, and evaluation. The scientific novelty of the study lies in the introduction of adapted earned value metrics for analyzing the achievement of SDGs at the portfolio and program levels. The practical value of the approach is its applicability to various industries, considering their unique environmental, social, and economic aspects. The proposed model allows project managers to enhance decision-making efficiency, optimize resource utilization, and improve transparency in project execution while meeting stakeholder requirements. The main research outcomes include formalizing interconnections between sustainable development indicators, resources, risks, and stakeholder requirements. The proposed approach supports strategic planning and the integration of sustainable development at all project stages and ensures long-term sustainability in managing portfolios and programs.

Keywords

Project Portfolios and Program management, Sustainable Development Goals, Monitoring

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1. Introduction

Today, sustainable development has become a key concept influencing all areas of human activity. Project management is no exception, where integrating sustainability principles requires project managers to effectively balance various priorities [1]. Project management oriented toward sustainable development not only aims to achieve business objectives but also considers environmental, social, and economic aspects [2].

Sustainable development encompasses three primary dimensions: environmental, social, and economic. Project management necessitates achieving results within budget and deadlines while minimizing negative environmental impacts and ensuring social responsibility [3].

The relevance of scientific research in this area is confirmed by the growing dynamics in the number of publications in scientific journals indexed in Scopus and Web of Science databases (Fig. 1). Most of these studies focus on three domains: Environmental Sciences Ecology, Science Technology Other Topics, and Engineering, followed by Business Economics, Water Resources, and Computer Science.

The main principles of project management are reflected in standards such as PMBOK [4], which describes classical approaches to project management, and GPM P5 [5], which focuses on

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sustainable development. Recent research in this field emphasizes integrating sustainability principles into management practices.

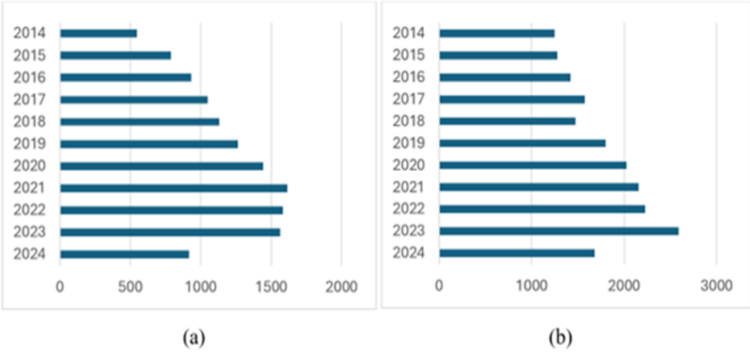

Figure 1: Dynamics of the number of articles in WoS (a) and Scopus (b) publications on the topic of sustainable project management (2014 – first half of 2024).

Artificial Intelligence has become a practical enabler for sustainable project management within this expansion [6]. Supervised and unsupervised learning support the prediction of sustainability indicators and early-warning signals. NLP helps extract stakeholder requirements and SDG evidence from unstructured documents. Fuzzy logic/knowledge-based AI operationalizes ambiguous linkages between work packages, indicators, and risks. These AI techniques complement classical methods and increase monitoring cadence without changing governance structures.

For instance, [7] examines the Earned Value Management (EVM) method and its modifications for monitoring construction projects. The proposed Sustainable Earned Value Management (SEVM) model enables project managers to plan, monitor, and control key project goals: work scope, timelines, costs, and sustainability indicators.

Multi-criteria analysis methods are also applied to assess the level of integration of sustainability philosophy into the activities of large organizations through sustainable project management indicators [8]. This approach evaluates the extent to which existing project management methodologies support the implementation of sustainability parameters across various sectors [9].

An important aspect is the inclusion of sustainability issues in management practices at the micro-level. For example, [10] explores effective ways to implement sustainability principles through localized practices, while [11] analyzes the role of project management offices in this context in detail.

Considering Sustainable Development Goals (SDGs) as critical success factors for projects also draws significant attention. A management model that incorporates these goals is proposed in [12].

Despite the growing focus on sustainability, research [13] indicates that integrating sustainability principles into project management remains at an early stage. Existing tools for assessing projects' impact on sustainable development often have limited practical effectiveness [14].

Overall, there is growing recognition of sustainable development as a strategic imperative for long-term success [14]. The results of a survey [15] further support this. Note that some studies focus on monitoring a specific sustainable development goal, such as [16].

One of the leading areas of research is sustainable development and management in construction [17], in particular the application of digital technologies to monitor construction projects [18].

Accordingly, the literature identifies the following research directions [19]:

1. Management of sustainable projects – the implementation of sustainable practices by companies.

2. Management of sustainable projects – the sustainable execution of projects.
3. Management of sustainable projects – the methodology for managing sustainable projects.
4. The role of stakeholders.
5. Sustainable Development Goals.

For instance, [20] defines 17 SDGs and 169 targets to eradicate poverty, reduce inequality, protect the planet, and ensure peaceful and prosperous lives for all. The document emphasizes the necessity of global partnerships, inclusivity, and accountability, highlighting that sustainable development must consider economic, social, and environmental aspects to achieve a harmonious future. To ensure Ukraine's national interests regarding sustainable development of the economy, civil society, and the state, a corresponding decree has been signed by the president [21].

Thus, an analysis of recent research indicates growing attention to integrating sustainability principles into project management and the necessity of considering them at all levels. In this context, our study aims to develop an approach for monitoring the execution of project portfolios and programs in terms of achieving sustainable development goals and ensuring alignment with contemporary challenges and strategic objectives.

This paper aims to develop an approach for monitoring the execution of project portfolios and programs to achieve sustainable development goals.

2. Research Methodologies

Previous studies [22] proposed tools that allow tracking the fulfillment of stakeholder requirements over time, considering their risk and resource constraints. These tools enhance decision-making efficiency regarding stakeholder interactions based on project requirement monitoring processes. A similar approach can be applied to track the achievement of sustainable development goals while executing a program or project portfolio.

It is worth noting that the following definitions will be used for portfolios and project programs: A program is a group of interrelated projects and various activities unified by a common objective and execution conditions. A portfolio is a set of projects and programs grouped for management convenience. Projects and programs within a portfolio may or may not share common objectives but generally have shared resource constraints.

Figure 2 complements the hierarchy of projects, portfolios, and programs by integrating each project's intersection area of the Work Breakdown Structure (WBS) and the Sustainable Development Goals Breakdown Structure (SGBS).

The hierarchy [20] establishes the foundation of SGBS, which can be further supplemented with sustainability indicators (e.g., a system for construction projects is presented in [7]).

The aforementioned area forms a matrix of control points for sustainability indicators. In the matrix field, a specific sustainability indicator (ISG, an element of SGBS) is mapped to a work element (work, an element of WBS) being performed to alter the value of that indicator.

Next, we define the metrics for the earned value method for program/portfolio requirements:

PIS – Planned Indicator of Sustainability: the planned amount of sustainability indicator performance (in monetary terms) expected to be completed at the time of the earned value report;

EIS – Earned Indicator of Sustainability: the actual amount of sustainability indicator performance (in monetary terms) completed by the time of the earned value report;

AC – Actual Cost: the actual amount of resources (in monetary terms) spent on project activities by the time of the earned value report;

SIS – Schedule Indicator of Sustainability Variance:

$$SIS = EIS - PIS \tag{1}$$

CIS – Cost Indicator of Sustainability Variance:

$$CIS = EIS - AC \tag{2}$$

SPIIS – Schedule Performance Index for Stakeholder Requirements:

$$SPIIS = \frac{EIS}{PIS} \tag{3}$$

CPIIS – Cost Performance Index for Stakeholder Requirements:

$$CPIIS = \frac{EIS}{AC} \tag{4}$$

It should be noted that, unlike applying the earned value method for a project, monitoring for a portfolio or program is only feasible over a specific period. This is especially true for project portfolios and programs, which may transform over time and thus lack a defined "start" or "finish" date.

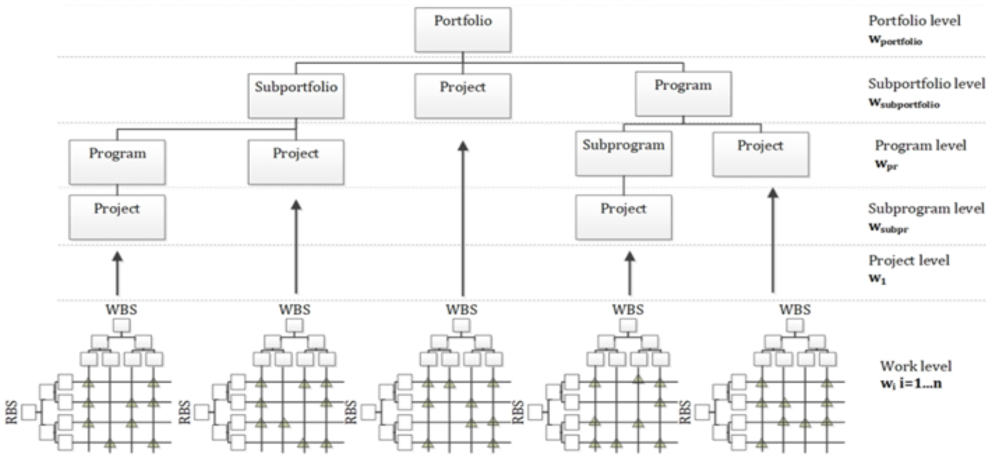

Figure 2: Hierarchy of Projects, Portfolios, and Programs.

Another significant difference is the inability to utilize reserves outside critical activities for a portfolio since projects that are not time-linked make the existence of a critical path impossible.

From the strategic planning perspective, the actionable level is the project level. Therefore, all principles developed for project can be extended from the level of specific project tasks to the level of the project, program, or portfolio.

Thus, the connections between elements of different hierarchy levels can be represented as a matrix, with elements indicating the presence or absence of a connection between an element at the i-th level and the (i - 1)-th level: F=1, if a connection exists, and F=0, if there is no connection:

$$M_{(i,i-1)} = \begin{bmatrix} F\left(w_{(i,1)}, w_{(i-1,1)}\right) & F\left(w_{(i,1)}, w_{(i-1,2)}\right) & \cdots & F\left(w_{(i,1)}, w_{(i-1,m)}\right) \\ F\left(w_{(i,2)}, w_{(i-1,1)}\right) & & & F\left(w_{(i,2)}, w_{(i-1,m)}\right) \\ \vdots & & & \vdots \\ F\left(w_{(i,n)}, w_{(i-1,1)}\right) & F\left(w_{(i,n)}, w_{(i-1,2)}\right) & \cdots & F\left(w_{(i,n)}, w_{(i-1,m)}\right) \end{bmatrix} \tag{5}$$

Connections at the project-subprogram level are defined as follows (the level codes are provided in Figure 2, the number of elements at level i is n, and at level (i-1) is m):

$$M_{(pr,subpr)} = \begin{bmatrix} F\left(w_{(pr,1)}, w_{(subpr,1)}\right) & F\left(w_{(pr,1)}, w_{(subpr,2)}\right) & \cdots & F\left(w_{(pr,1)}, w_{(subpr,m)}\right) \\ F\left(w_{(pr,2)}, w_{(subpr,1)}\right) & & & F\left(w_{(pr,2)}, w_{(subpr,m)}\right) \\ \vdots & & & \vdots \\ F\left(w_{(pr,n)}, w_{(subpr,1)}\right) & F\left(w_{(pr,n)}, w_{(subpr,2)}\right) & \cdots & F\left(w_{(pr,n)}, w_{(subpr,m)}\right) \end{bmatrix} \tag{6}$$

Connections at the subprogram-program level:

$$M_{(subpк,pr)}=\begin{bmatrix} F\left(w_{(subpr,1)},w_{(pr,1)}\right) & F\left(w_{(subpr,1)},w_{(pr,2)}\right) & \cdots & F\left(w_{(subpr,1)},w_{(pr,m)}\right) \\ F\left(w_{(subpr,2)},w_{(pr,1)}\right) & & & F\left(w_{(subpr,2)},w_{(pr,m)}\right) \\ \vdots & & & \vdots \\ F\left(w_{(subpr,n)},w_{(pr,1)}\right) & F\left(w_{(subpr,n)},w_{(pr,2)}\right) & \cdots & F\left(w_{(subpr,n)},w_{(pr,m)}\right) \end{bmatrix} \quad (7)$$

Connections at the program-subportfolio level:

$$M_{(subport,pr)}=\begin{bmatrix} F\left(w_{(subpor,1)},w_{(pr,1)}\right) & \cdots & F\left(w_{(subpor,1)},w_{(pr,m)}\right) \\ F\left(w_{(subpor,2)},w_{(pr,1)}\right) & \cdots & F\left(w_{(subpor,2)},w_{(pr,m)}\right) \\ \vdots & & \vdots \\ F\left(w_{(subpor,n)},w_{(pr,1)}\right) & \cdots & F\left(w_{(subpor,n)},w_{(pr,m)}\right) \end{bmatrix} \quad (8)$$

Connections at the subportfolio-portfolio level:

$$M_{(port,subpor)}=\begin{bmatrix} F\left(w_{(port,1)},w_{(subpor,1)}\right) & \cdots & F\left(w_{(port,1)},w_{(subpor,m)}\right) \\ F\left(w_{(port,2)},w_{(subpor,1)}\right) & \cdots & F\left(w_{(port,2)},w_{(subpor,m)}\right) \\ \vdots & & \vdots \\ F\left(w_{(port,n)},w_{(subpor,1)}\right) & \cdots & F\left(w_{(port,n)},w_{(subpor,m)}\right) \end{bmatrix} \quad (9)$$

The input data for formalization consists of the hierarchy of the portfolio or program. During the study, this hierarchy is supplemented with information on resource allocation and responsible individuals for specific projects (these connections are explicitly available during project planning) and data on the distribution of sustainable development indicators and risks across projects (such data are typically unavailable in an explicit form, so it is proposed to model the corresponding connections using fuzzy set methods).

We introduce the following notations:

$Resource_i$ – matrix of resource allocation for the i-th level of the hierarchical structure;

$resource_k$ – the k-th resource;

R(esource)BS – hierarchical structure of resources;

ISBS – matrix of sustainable development indicator distribution for the i-th level of the hierarchical structure;

is_l – the l-th sustainable development indicator;

SGBS – hierarchical structure of sustainable development goals;

$Responsibility_i$ – matrix of responsibility distribution for the i-th level of the hierarchical structure;

$responsibility_z$ – the z-th responsible individual;

R(esponsibility)BS – organizational structure of the portfolio/program/project;

$Risk_i$ – matrix of risk distribution for the i-th level of the hierarchical structure;

$risk_v$ – the v-th risk;

R(isk)BS – hierarchical structure of risks;

ISRec – matrix of the relationship between sustainable development indicators and the resources required for their modification;

ISRes – matrix of the relationship between sustainable development indicators and the individuals responsible for their implementation;

ISRis – matrix of the relationship between sustainable development indicators and the risks associated with their implementation;

S – matrix of sustainable development indicator distribution among stakeholders;

str_u – the u-th stakeholder of the portfolio/program/project;

Φ – function describing the relationship between two elements of the model in a fuzzy form.

Each structure element can be associated with specific resource loads, sustainable development indicators supported by the element, responsible performers, and risks linked to the element. These connections can also be expressed in matrix form:

- the relationship between resources and elements at the i-th level. Each matrix element is defined as a fraction of the total volume of a specific resource used for the execution of the element,

$$Resource_i = \begin{bmatrix} F\left(resource_1, w_{(i,1)}\right) & \cdots & F\left(resource_1, w_{(i,n)}\right) \\ F\left(resource_2, w_{(i,1)}\right) & \cdots & F\left(resource_2, w_{(i,n)}\right) \\ \vdots & & \vdots \\ F\left(resource_k, w_{(i,1)}\right) & \cdots & F\left(resource_k, w_{(i,n)}\right) \end{bmatrix} \tag{10}$$

- the relationship between responsible individuals and an element at the i-th level: A matrix element equals 1 if a specific individual executes the element or 0 otherwise,

$$Responsibility_i = \begin{bmatrix} F\left(responsibility_1, w_{(i,1)}\right) & \cdots & F\left(responsibility_1, w_{(i,n)}\right) \\ F\left(responsibility_2, w_{(i,1)}\right) & \cdots & F\left(responsibility_2, w_{(i,n)}\right) \\ \vdots & & \vdots \\ F\left(responsibility_z, w_{(i,1)}\right) & \cdots & F\left(responsibility_z, w_{(i,n)}\right) \end{bmatrix} \tag{11}$$

- the relationship between sustainable development indicators and an element at the i-th level: This relationship can be expressed in a fuzzy form.

$$ISBS_i = \begin{bmatrix} \Phi\left(is_1, w_{(i,1)}\right) & \cdots & \Phi\left(is_1, w_{(i,n)}\right) \\ \Phi\left(is_2, w_{(i,1)}\right) & \cdots & \Phi\left(is_2, w_{(i,n)}\right) \\ \vdots & & \vdots \\ \Phi\left(is_l, w_{(i,1)}\right) & \cdots & \Phi\left(is_l, w_{(i,n)}\right) \end{bmatrix} \tag{12}$$

- the relationship between risks and an element at the i-th level: This relationship can also be expressed in a fuzzy form.

$$Risk_i = \begin{bmatrix} \Phi\left(risk_1, w_{(i,1)}\right) & \cdots & \Phi\left(risk_1, w_{(i,n)}\right) \\ \Phi\left(risk_2, w_{(i,1)}\right) & \cdots & \Phi\left(risk_2, w_{(i,n)}\right) \\ \vdots & & \vdots \\ \Phi\left(risk_v, w_{(i,1)}\right) & \cdots & \Phi\left(risk_v, w_{(i,n)}\right) \end{bmatrix} \tag{13}$$

Establishing a connection between stakeholders and sustainable development indicators is also possible:

$$S = \begin{bmatrix} F\left(str_1, is_1\right) & \cdots & F\left(str_1, is_l\right) \\ F\left(str_2, is_1\right) & \cdots & F\left(str_2, is_l\right) \\ \vdots & & \vdots \\ F\left(str_u, is_1\right) & \cdots & F\left(str_u, is_l\right) \end{bmatrix} \tag{14}$$

Using the formulas provided above, we derive the distribution of the characteristics (model elements) being studied across the (i-1)-th level of the portfolio hierarchy:

- Resources: $Resource_{i-1} = M_{i,i-1} \cdot Resource_i$;
- Responsibilities: $Responsibility_{i-1} = M_{i,i-1} \cdot Responsibility_i$;
- Sustainable development indicators: $Requirement_{i-1} = M_{i,i-1} \cdot ISBS_i$;
- Risks: $Risk_{i-1} = M_{i,i-1} \cdot Risk_i$.

This allows for establishing relationships between specific characteristics. For example, the following formulas link sustainable development indicators to the resources required for their implementation, the responsible individuals, and the risks that may arise during project execution: $RRec = ISBS_{i-1}^T \cdot Resource_{i-1}$, $RRes = ISBS_{i-1}^T \cdot Responsibility_{i-1}$, $RRis = ISBS_{i-1}^T \cdot Risk_{i-1}$.

Subsequently, using information about sustainable development indicators, it becomes possible to correlate individual indicators' resource and risk loads with the corresponding stakeholders. This enables the classification of portfolio/program stakeholders based on these characteristics.

Models of the process for monitoring the achievement of sustainable development goals in project portfolios and programs management are presented in Figures 3 and 4.

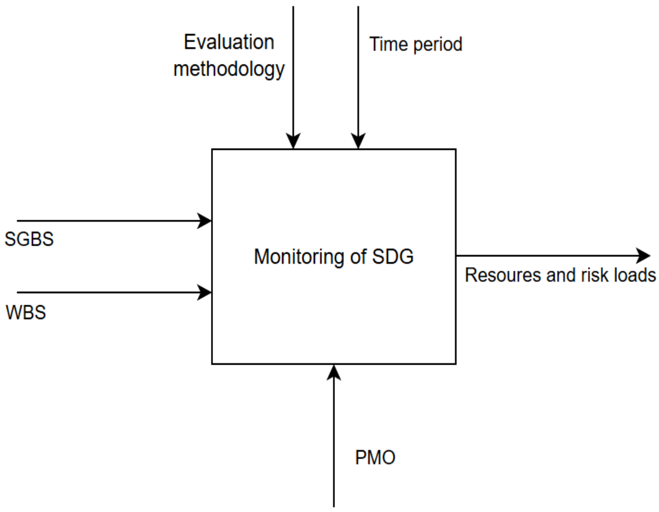

Figure 3: Contextual model of the process for monitoring the achievement of sustainable development goals in project portfolios and programs management.

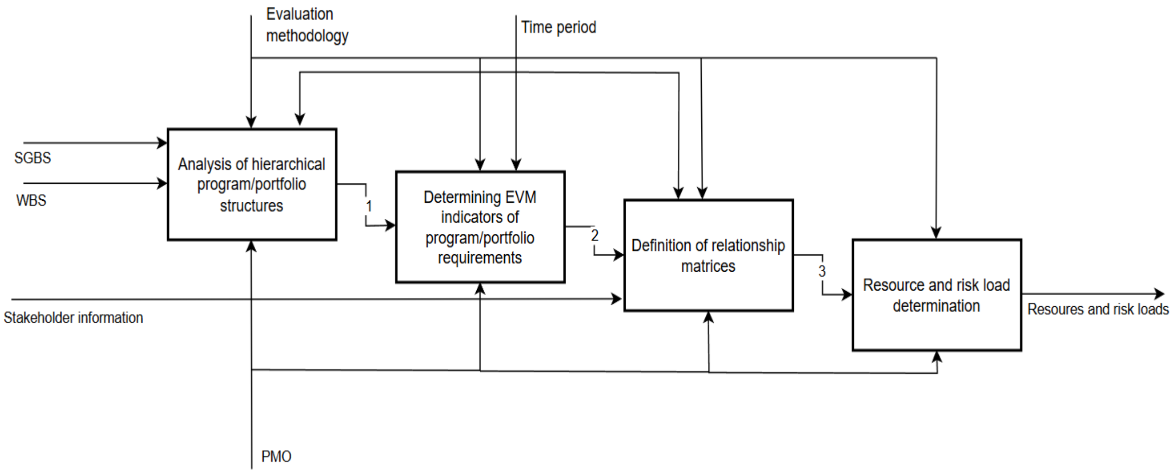

Figure 4: Decomposition model of the process for monitoring the achievement of sustainable development goals in project portfolios and programs management: 1 – Matrix of control points of

sustainable development indicators; 2 – EVM indicators of program/portfolio requirements; 3 – Relationship matrices.

3. Results and Discussion

Let us consider a hypothetical hierarchical structure presented in Figure 5. The program consists of three projects, with the highest WBS level for, each being the third level of the hierarchical structure.

Assume the program uses three types of resources (resource1, resource2, resource3), distributed among the third-level tasks as follows:

$$Resource_3 = \begin{matrix} 0,2 & 0,05 & 0 \\ 0,5 & 0 & 0,4 \\ 0,1 & 0,55 & 0 \\ 0,2 & 0 & 0,1 \\ 0 & 0,4 & 0,2 \\ 0 & 0,05 & 0,3 \end{matrix}$$

and the program addresses two sustainable development indicators (is1, is2), distributed among the elementary tasks of the projects as follows:

$$ISBS_3 = \begin{matrix} 0 & 0,3 \\ 0,5 & 0 \\ 0 & 0,6 \\ 0,25 & 0 \\ 0,25 & 0 \\ 0 & 0,1 \end{matrix}$$

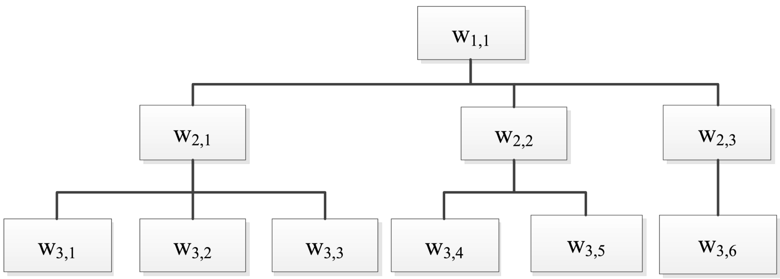

Figure 5: Hierarchical structure of the program.

Connections between elements at the third and second levels are described by the matrix M32:

$$M_{32} = \begin{matrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{matrix}$$

Connections between the second and first levels are defined by the vector M21: $M_{21} = 1 \quad 1 \quad 1$

The analysis is conducted at the second level: Resource distribution for the second level

$$Resource_2 = M_{32} \cdot Resource_3 = \begin{matrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{matrix} \cdot \begin{matrix} 0,2 & 0,05 & 0 \\ 0,5 & 0 & 0,4 \\ 0,1 & 0,55 & 0 \\ 0,2 & 0 & 0,1 \\ 0 & 0,4 & 0,2 \\ 0 & 0 & 0,3 \end{matrix} = \begin{matrix} 0,8 & 0,6 & 0,4 \\ 0,2 & 0,4 & 0,3 \\ 0 & 0 & 0,3 \end{matrix}$$

- Distribution of sustainable development indicators for the second level:

$$ISBS_2 = M_{23} \cdot ISBS_3 = \begin{matrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{matrix} \cdot \begin{matrix} 0 & 0,3 \\ 0,5 & 0 \\ 0 & 0,6 \\ 0,25 & 0 \\ 0,25 & 0 \\ 0 & 0,1 \end{matrix} = \begin{matrix} 0,5 & 0,9 \\ 0,5 & 0 \\ 0 & 0,1 \end{matrix}$$

- Relationship between sustainable development indicators and resources for the second level:

$$RRec = ISBS_3^T \cdot Resource_3 = \begin{matrix} 0,5 & 0,5 & 0 \\ 0,9 & 0 & 0,1 \end{matrix} \cdot \begin{matrix} 0,8 & 0,6 & 0,4 \\ 0,2 & 0,4 & 0,3 \\ 0 & 0 & 0,3 \end{matrix} = \begin{matrix} 0,5 & 0,5 & 0,35 \\ 0,72 & 0,54 & 0,39 \end{matrix}$$

Thus, the resource load for a specific sustainable development indicator is determined: The first indicator consumes 0.5 of the first resource; 0,5 of the second resource and 0,35 of the third resource; for the second indicator, the resource consumption values are 0.72, 0.54, and 0.39, respectively.

The matrix RRec does not account for the distribution of "shared" resources among individual indicators. On the other hand, the column sums of this matrix reflect the efficiency of resource use for achieving the indicators. The efficiency values are: 1.32 for resource1, 1.04 for resource2, 0.74 for resource3.

To account for shared resource usage, the resource load is calculated separately for the first indicator:

$$\begin{matrix} 0,4 & 0,3 & 0,2 \\ 0,1 & 0,2 & 0,15 \\ 0 & 0 & 0 \end{matrix}$$

and for the second indicator:

$$\begin{matrix} 0,72 & 0,54 & 0,36 \\ 0 & 0 & 0 \\ 0 & 0 & 0,03 \end{matrix}$$

Thus, the first indicator consumes resources:

$$\begin{matrix} 0,2 & 0,15 & 0,1 \\ 0,1 & 0,2 & 0,15 \\ 0 & 0 & 0 \end{matrix}$$

and the second indicator consumes

$$\begin{matrix} 0,52 & 0,39 & 0,26 \\ 0 & 0 & 0 \\ 0 & 0 & 0,03 \end{matrix}$$

Relationship between sustainable development indicators and resources for the second level, accounting for shared resource usage (assuming equal distribution):

$$\begin{vmatrix} 0{,}3 & 0{,}35 & 0{,}25 \\ 0{,}52 & 0{,}39 & 0{,}29 \end{vmatrix}$$

Similarly, matrices for the relationship between sustainable development indicators and the individuals responsible for their implementation, as well as matrices for the relationship between indicators and risks arising during project execution, can be derived.

It should be noted that existing methods model only the relationships between tasks and project resources, separating time resources. Practical implementations of such methods include project management software, such as MS Project, OpenProj, and Gantter for traditional project management, and Jira and Trello for agile development methodologies.

4. Conclusion

The research demonstrated the importance of integrating sustainable development principles into the processes of managing project portfolios and programs. The proposed approach, based on the combination of the Work Breakdown Structure (WBS) with the Sustainable Development Goals Indicator System (SGBS), enables systematic monitoring of the achievement of Sustainable Development Goals (SDGs). This facilitates control over key project aspects, such as their economic, environmental, and social impacts, and enhances the transparency of managerial decisions. The results also confirm the effectiveness of using adapted earned value metrics to assess progress in achieving sustainable development indicators. The developed metrics help identify resource, time, and risk constraints in projects, optimizing interactions among stakeholders.

Future research directions could include extending the proposed model to account for the specifics of various industries, developing tools for real-time assessment of project impacts, and improving methods for modeling relationships between sustainable development indicators. These directions will aid in adapting project management to the evolving challenges of sustainable development, strengthening its role in achieving global goals.

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Declaration on Generative AI

During the preparation of this work, the authors used GPT-4 in order to: Grammar and spelling check. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the publication’s content.

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