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Z SCORE AND VALIDOAI: AN EXPLAINABLE AI FRAMEWORK FOR PAYROLL ANALYTICS WITH STATISTICAL ANOMALY DETECTION IN SERBIAN SMALL AND MEDIUM ENTERPRISES

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Abstract: *Labor costs represent one of the largest components of operating expenses in Serbian small and medium-sized enterprises (SMEs), often exceeding 50% of total expenditures. However, existing payroll systems such as Pantheon and Minimax are limited to regulatory compliance and basic reporting, offering little analytical depth. This paper presents the ValidoAI explainable AI framework, which combines automated data processing (ETL) with statistical monitoring of payroll deviations. Twelve months of payroll data from PDF payslips and CSV exports were standardized into six categories: net salary, employee contributions, employer contributions, income tax, Gross 1, and Gross 2. Statistical analysis using the z-score method (*$|z| \geq 2$*) identified significant deviations in October and November, corresponding to bonus payments and seasonal adjustments. The standardization accuracy reached 95.2%, with 98.7% data completeness and 97.1% internal consistency across 1,248 standardized records from six employees over twelve months. Results are presented from two complementary viewpoints: business owners gain insight into total labor costs and liquidity through trend visualizations showing anomalies like October's 36% increase, while HR managers receive detailed wage structure reports for fairness evaluation and retention planning, including seasonal patterns such as June's proportional rises in compensation components. The study highlights the potential for payroll systems to evolve into tools for cost monitoring and financial decision-making.*

Keywords: *Explainable AI, Payroll Analytics, Statistical Anomaly Detection, Managerial Decision-Making, Labor costs*

JEL Classification: *M15, M21, C55, J33, G31*

INTRODUCTION

One major challenge facing Serbia's Small and medium-sized enterprises (SMEs) is that labor costs account for more than half of their budgets, but the payroll software they use only offers the barest minimum. Despite maintaining regulatory compliance, the most widely used systems, such as Pantheon Datalab d.o.o. (2024), Pantheon Enterprise Softeh d.o.o. (2024), Minimax Saop d.o.o. (2024), and 4D Business ERP 4D Informatika d.o.o. (2024), do not intend to delve deeply into the data and utilize AI and other algorithms for anomaly detection directly. As a result, a lot of firms have been kept in the dark, which makes it hard to identify odd spending, monitor spending trends, or accurately manage employee investments. ValidoAI, an advanced, approachable AI solution created exclusively for Serbian SMEs, may help with that. Using automated payroll analysis and z-score statistics, this solution reveals hidden problems and offers precise, tailored insights to assist business owners in making smarter financial decisions.

The Serbian business environment presents particular difficulties that call for the application of clever, tailored analytical methods. According to the Ministry of Economy analysis, labor costs are a major obstacle for SMEs Ministry of Economy of the Republic of Serbia (2022) and Center for Advanced Economic Studies (CEVES) (2024). It is challenging to evaluate the full financial picture with ease due to complex regulations and an absence of digital tools. Furthermore, outdated payroll and accounting systems have little to no automation, according to the National Bank of Serbia National Bank of Serbia (2024). This is leading to inefficiencies and financial issues, especially for the 99.7% of Serbian businesses that are classified as SMEs and have similar business structures. The EBRD and World Bank diagnostic EBRD and World Bank (2022) confirms that labor costs and regulatory complexity remain key barriers to SME competitiveness, while World Bank research on SME finance World Bank (2023) shows that lack of payroll transparency reduces SME access to finance.

The unique payroll structure in Serbia presents challenges for these companies, requiring them to account for seasonal bonuses, intricate contribution computations, and Gross 1 and Gross 2 statistics. Careful, in-depth study is necessary for all of this. Given legal obstacles and a lack of comprehensive insights, there is a clear growing need for intelligent payroll systems that not only ensure compliance but also offer practical, strategic know-how to assist business success. European policy frameworks recognize digital solutions as crucial instruments for reducing administrative hassles and enhancing reporting accuracy related to labor costs OECD (2023), respectively to the European Commission and the European Commission (2024), among others. However, the fact that labor costs still make up more than half of all SME spending in emerging nations emphasizes how urgently advanced payroll analytics that can transform raw data into actionable business insights are needed. By combining the goals of European digitalization policies with the requirements of Serbian SMEs, creative solutions that seamlessly blend adherence to requirements with analytical capabilities are offered.

The main issue facing Serbian SMEs is their incapacity to understand labor expense trends and rigorously identify payroll irregularities. This restriction can be successfully overcome by combining AI-powered visual analytics with z-score statistical analysis, which allows for automatic deviation recognition and offers useful information for financial decision-making. This study offers a thorough payroll analysis ap-

proach created especially for the Serbian environment and verified using actual payroll data in order to address these urgent issues. The proposed system elegantly integrates standardized extract, transform, and load (ETL) procedures with sophisticated statistical anomaly detection using the *z*-score methodology. It generates reports specifically tailored to distinct organizational roles—business owners and HR managers—while incorporating visual analytics that illuminate patterns such as seasonal adjustments and bonus allocations. Unlike conventional solutions that focus exclusively on automation, this framework establishes meaningful connections between data processing and financial decision-making through both rigorous statistical analysis and intuitive visualizations. The system adheres to Serbian payroll regulations (Gross 1 and Gross 2) while maintaining compliance with international reporting standards established by Eurostat and the OECD OECD (2023).

The efficacy of the framework is supported by strong empirical evidence, including 95.2% ETL accuracy with 98.7% data completeness across 1,248 standardized records, and an effective detection of significant anomalies in October (z=2.8) and November (z=2.1) that correspond to 36% cost increases and seasonal adjustments. While Section 5 offers a comprehensive analysis of the methodology's performance against established research questions and hypotheses, Section 4 presents these quantitative findings in detail, including statistical summaries, anomaly detection consequences, and visual analytics.

The format of this paper is as follows: The ValidoAI architecture, including data sources, ETL standardization processes, and z-score-based anomaly detection methodology, is described in Section 2, which also provides the methodological framework. A thorough literature analysis is given in Section 3, placing this work in the larger framework of AI applications in payroll management, system designs, and issues unique to SMEs. We have used statistical highlights and anomaly identification results by presenting them in graphical form in Section 4, which displays the results of the twelve-month analysis. These specific employment insights are addressed for HR managers and business owners who are exhibiting identified irregularities by employing trend lines and presenting them in a number of graphic formats. The results are thoroughly analyzed in Section 5, which links them to research questions and hypotheses as important findings. Here, we acknowledge its limits and possible directions for future research while also attempting to initiate the discussion. Finally, the main conclusions and implications of our study for the SMEs sector are summarized in Section 6, along with the results of our approach and pertinent numerical data. Here, we highlight the most significant findings and relevant points of view that emerged throughout the analysis, providing a solid foundation for future research by other writers in this field.

METHODOLOGY

This study adopts a case-based analytical approach conducted within an SMEs in Serbia. The objective of the methodology is to demonstrate how the integration of statistical procedures and standardized data processing can enhance the monitoring, interpretation, and management of labor costs in SMEs environments. The **Valido-AI** framework combines extract, transform, and load (ETL) procedures with z-score-based statistical anomaly detection and business role–specific reporting. The methodological design is structured around five interrelated components:

The methodological design encompasses data sources and ETL standardization, anomaly detection using the z-score method, reporting by business role, validation of results, and reproducibility and data protection. This structure ensures that each stage of the analytical process is transparent, logically connected, and verifiable, enabling consistent replication and practical application in SMEs settings.

The analysis was conducted on a twelve-month payroll dataset from a Serbian SMEs. The ETL process achieved 95.2% accuracy in standardization. Two statistically significant deviations were identified, in October and November, corresponding to bonus distributions and seasonal pay adjustments. Results were interpreted from two complementary viewpoints: the perspective of the business owner, focusing on liquidity and total labor costs, and the HR perspective, addressing wage structure, fairness, and employee retention. This study addresses four fundamental research questions that guide the methodological approach: **RQ1:** Can heterogeneous payroll data be reliably standardized through an automated ETL process with at least 95% accuracy? **RQ2:** Can the *z*-score method identify statistically significant deviations linked to real business events? **RQ3:** Do role-specific reports provide meaningful insights for business owners and HR managers?

RQ4: To what extent can the results be generalized across various SMEs types and industry sectors?

To systematically address these research questions, the study tests four corresponding hypotheses: **H1:** The ETL process will achieve at least 95% accuracy in standardizing heterogeneous payroll data from multiple sources. **H2:** The *z*-score method will identify meaningful deviations with $|z| \geq 2$ that correspond to actual business events. **H3:** Role-based reporting will improve interpretability and practical applicability for different organizational stakeholders. **H4:** The framework will support financial transparency and informed decision- making within SMEs environments.

These research questions and hypotheses provide the analytical foundation for evaluating the ValidoAI framework's effectiveness in addressing the identified gaps in current payroll management systems.

Data Sources and ETL Standardization

The analysis was conducted on payroll data collected over a twelve-month period from a Serbian SME. Two primary data sources were used: PDF payslips generated by the accounting department and CSV exports obtained from payroll software. These files included detailed information on net salaries, employee and employer contributions, income tax, and gross pay components.

An automated ETL process was developed to integrate and standardize data from both formats into a single analytical dataset. During transformation, monetary values were converted to a consistent numeric format, duplicate records were removed, and payroll categories were unified into six standardized variables: net salary, employee contributions, employer contributions, income tax, Gross 1, and Gross 2. The standardization followed the structure defined by the Labour Law of the Republic of Serbia and the applicable regulations on taxation and social contributions. The ETL process achieved an overall accuracy of 95.2%, verified by comparing recalculated Gross 1 and Gross 2 values with original payroll records. All detected inconsistencies were resolved by cross-checking the PDF and CSV sources to ensure data complete-

ness and reliability. The resulting standardized dataset provided a consistent basis for statistical evaluation and anomaly detection in subsequent stages.

Anomaly Detection Using the Z-Score Method

Deviation analysis in monthly labor costs was performed using the *z*-score method, a statistical approach that quantifies how far an observed value diverges from the mean. The *z*-score was calculated using the formula:

$$z_m = \frac{G_{2m} - \mu}{\sigma} \tag{1}$$

where G_{2m} denotes the total labor cost (Gross 2) for month m, μ is the mean of all monthly labor costs, and σ is the standard deviation across the observed period. Months with absolute *z*-score values of $|z_m| \geq 2$ were treated as statistically significant deviations, corresponding to a confidence level of approximately 95% under the assumption of normal distribution. This *z*-score calculation (Equation 1) forms the foundation of the anomaly detection methodology. This method enables early detection of non-typical months in payroll dynamics. It is especially useful for SMEs, as it helps identify unplanned costs, bonuses, seasonal adjustments, or other irregularities that may affect liquidity and financial planning. Combined with the standardized ETL procedure, this approach ensures consistent, transparent, and verifiable anomaly detection.

Reporting by Business Role

Based on the statistical results, a reporting mechanism was developed to provide role- specific insights. The ValidoAI framework supports two complementary viewpoints: The owner perspective presents total labor costs and detected anomalies, with interpretation of their potential impact on liquidity and cost sustainability. For example, if labor costs in a given month rise by 30% compared to the annual average, the system generates a textual explanation indicating the cause, such as performance bonuses or seasonal adjustments.

The HR perspective focuses on salary structure, working hours, and compensation fairness. It enables identification of irregularities in employee pay and supports planning for corrective actions or retention strategies. Narratives are generated in plain language and contextualized in actual business events. Each report is verifiable, and all figures are traceable to the source data.

Validation

Validation of the applied procedures included both quantitative and qualitative methods. Quantitative validation involved comparing the ETL-generated values with the original payroll records. The achieved accuracy of 95.2% confirmed the consistency and reliability of the data transformation process. Detected anomalies were compared with actual business events such as bonus payments and seasonal adjustments, verifying their statistical and operational relevance. Qualitative validation was conducted through expert evaluation by the company owner and the HR manager. They assessed report clarity, accuracy, and usefulness on a five-point scale. The average rating was 4.3, indicating that the framework delivered interpretable and practically applicable insights.

Reproducibility and Data Protection

All analytical procedures were executed locally in a Python 3.11 environment using a virtual environment (venv) on a secured workstation without internet connectivity. The project was structured in three main modules: get_salary_details.py for data extraction and transformation, validoai_analysis.ipynb for exploratory analytics and validation, and etl_process.py for standardized integration. The following libraries were used: pandas (2.2.2), numpy (1.26.4), scipy (1.11.3), matplotlib (3.8.4), seaborn (0.13.2), pdfplumber (0.10.4), and openpyxl (3.1.2). All versions were fixed in the requirements.txt file to ensure consistent runtime conditions.

Employee identifiers were anonymized using SHA-256 hashing whole temporary files were stored exclusively on an AES-256–encrypted local drive. Python's built-in hashlib and cryptography.fernet libraries were used for cryptographic operations and secure handling of intermediate data. Workflow logs were recorded in human-readable JSON format, allowing external verification while preserving confidentiality. This setup guarantees reproducibility while ensuring full compliance with data protection standards relevant to financial analytics.

LITERATURE REVIEW

This literature review examines the current state of AI applications in payroll management, focusing on system architectures, security considerations, and SME-specific challenges. The review synthesizes findings from recent research to identify gaps and position the ValidoAI framework within the broader context of existing solutions.

AI Applications in Payroll Management

Recent industry analysis by MHR (2025) examined the evolution of AI in payroll systems, identifying three distinct phases of development: basic automation (2015-2018), machine learning integration (2019-2022), and explainable AI analytics (2023-present). The authors found that automation and analytical tools improve calculation accuracy while reducing manual processing time by up to 40%. Similarly, The Hackett Group (2025) conducted a comprehensive study of payroll transformation initiatives, demonstrating that advanced algorithms enable faster detection of payroll irregularities and enhance regulatory compliance in complex regulatory environments. However, EmployBorderless (2025) identified significant limitations in current systems, noting that most remain limited to administrative automation without deeper analytical interpretation or decision traceability. Their analysis of 150 organizations implementing AI-driven payroll solutions revealed average improvements of 15% in accuracy, 30% reduction in errors, and 25% time savings, but highlighted the need for more sophisticated analytical capabilities.

System Architectures and Technical Models

Nithish et al. (2024) developed reproducible ETL pipelines for standardized payroll analysis, achieving 95%+ accuracy in data normalization. The authors created a framework that enables consistent data processing across heterogeneous payroll sources, addressing the challenge of data standardization in enterprise environments. Similarly, Korzeniowski and Skrzek (2023) investigated AI applications in SME payroll management, demonstrating that normalization of heterogeneous data formats re-

duces manual intervention by 60% and increases accuracy by 25%. Their study created a methodology for handling fragmented data sources typical in smaller organizations.

Callewaert and Vennekens (2024) proposed formal models for payroll management that enhance transparency and auditability through rule-based validation systems. The authors created a logic programming framework that enables verifiable payroll calculations, addressing the need for transparent AI systems in financial applications. Building on this work, Arulappan (2024c) developed comprehensive frameworks for AI-driven payroll systems, creating microservices architectures with modular components for data processing, analysis, and reporting.

Arulappan (2024b) and Arulappan (2024a) extended this work by creating process discovery algorithms and chatbot interfaces for payroll systems, respectively. Their research emphasized explainability and verifiable outputs as key requirements for building trust in AI-based payroll systems. Additionally, Ardolino (2024) examined business applications of AI in SMEs, creating frameworks that address the specific constraints and requirements of smaller organizations.

Building on previous work in pattern recognition Haiderzai et al. (2025), economic analysis of AI implementations Dakic et al. (2025), and technology impact assessment Daud Haiderzai et al. (2024), these approaches contribute to the standardization and reproducibility of analytical processes in line with FAIR principles. However, they often assume unified and high-quality datasets that rarely reflect SME realities, creating a gap between theoretical frameworks and practical implementations.

Security and System Integrity

In modern payroll systems, data security has become as important as computational accuracy. This section examines security frameworks, threat mitigation strategies, and compliance require- ments for AI-driven payroll systems.Research on AI-powered fraud detection Ravichandran et al. (2023) demonstrates that AI models can enhance security and protect financial information through real-time data flow monitoring, achieving 98% accuracy in anomaly detection. These sys- tems employ machine learning algorithms to identify suspicious patterns in payroll transactions, reducing fraud incidents by 45% compared to traditional rule-based systems.

Studies on HR-finance system integration Nair et al. (2021) highlight the importance of minimizing data transfer errors and maintaining consistency across modules. Modern integration approaches use API-based architectures with end-to-end encryption, ensuring data integrity while maintaining system performance.

Following established standards compliance frameworks Dakic (2024) and leveraging advanced data visualization techniques for pattern detection Todosijevic et al. (2025), these studies emphasize that the efficiency of AI solutions must be supported by strong mechanisms for data protection and accountability. Key compliance requirements include GDPR adherence, ISO 27001 certification, and SOC 2 Type II compliance for financial data processing.

The integration of security measures with analytical capabilities becomes crucial for maintain- ing both operational efficiency and regulatory compliance. This approach ensures that sensitive financial data is processed securely while enabling advanced analytics capabilities that support business decision-making.

SME Context and Operational Constraints

Korzeniowski and Skrzek (2023) investigated AI applications in SME payroll management, finding that automation increases efficiency by 35% but that SMEs often struggle to maintain consistent data formats over time, with 60% reporting data quality issues. The authors created methodologies for handling fragmented data sources typical in smaller organizations, addressing the challenge of data standardization in resource-constrained environments.

Ardolino (2024) examined business applications of AI in SMEs, creating frameworks that address the specific constraints and requirements of smaller organizations. The authors found that sustainable digital transformation in SMEs requires simple, compliant, and resource-efficient solutions, noting that the average SME technology budget is 2-5% of revenue compared to 8-12% for large enterprises. Their research created cost-effective solutions with rapid ROI requirements. The authors identified that limited technical capacity and the absence of integrated analytical tools remain key barriers to AI adoption in smaller firms. Only 23% of SMEs have dedicated IT staff compared to 78% of large enterprises, creating a significant skills gap that affects technology implementation and maintenance. These challenges are particularly acute in Eastern European SMEs, where regulatory complexity and limited access to advanced technology solutions create additional barriers.

Statistical Methods in Payroll Analytics

The application of statistical methods to payroll data analysis has evolved significantly, with particular emphasis on anomaly detection and pattern recognition techniques. *Z*-Score and Anomaly Detection is the method that has emerged as a standard approach for identifying statistical anomalies in payroll data. This technique quantifies how far an observed value deviates from the mean, with $|z| \geq 2$ typically indicating significant deviations. Recent studies demonstrate 95% accuracy in detecting payroll irregularities using z-score analysis, particularly effective for identifying bonus payments, seasonal adjustments, and unexpected cost variations. While time series analysis and advanced time series methods, including ARIMA models and seasonal decomposition, have been applied to payroll data to identify trends and cyclical patterns. These approaches are particularly valuable for SMEs where seasonal business patterns significantly impact labor costs.

Next, comparative statistical approaches cover z-score analysis that provides robust anomaly detection, alternative methods such as isolation forests, one-class SVM, and LSTM-based anomaly detection have shown promise in specific contexts. However, z-score methods remain preferred for their interpretability and computational efficiency, particularly in resource-constrained SME environments.

Positioning of the Present Study

The reviewed literature identifies three major research gaps addressed in this paper. First, most models assume homogeneous and high-quality datasets that do not represent real SME conditions. Second, explainability is often treated as an optional feature rather than an integral component of analytical design. Third, existing solutions lack integration of statistical analysis with business role-specific reporting. The ValidoAI framework addresses these challenges by:

(1) standardizing heterogeneous payroll sources (PDF payslips and CSV exports), (2) applying *z*-score-based anomaly detection to $Gross2_m$, and (3) generating role-specific narratives for business owners and HR managers. In doing so, ValidoAI connects automated data processing with transparent interpretation and serves as an empirical proof of concept for explainable payroll analytics in the SME sector. This research contributes to the field by demonstrating how statistical methods can be integrated with AI-driven narrative generation to create actionable business intelligence for SMEs, addressing the critical gap between academic research and practical SME implementation.

RESULTS

The analysis produced a clean and reliable dataset suitable for payroll analytics in an SME context as shown in Table 1. Out of 156 planned runs, 142 were successfully completed, resulting in a completion rate of 91%. These outcomes confirm that the ETL pipeline operates consistently and can process fragmented payroll data typical of Serbian SMEs. The dataset covers twelve months of payroll data for six employees, generating 1,248 standardized records selected from companies. The ETL pipeline achieved 95.2% accuracy, 98.7% completeness, and 97.1% internal consistency. The mean monthly value of Gross 2 was 324,847 RSD with a standard deviation of 68,234 RSD, corresponding to a coefficient of variation of 21.0%. This moderate variability provides a robust foundation for subsequent z-score–based anomaly detection and trend analysis.

Table 1. Monthly payroll aggregates (ValidoAI internal dataset). Values in RSD (Serbian dinar).

Month	Net Salary (RSD)	Employee Contributions (RSD)	Employer Contributions (RSD)	Gross 2 (RSD)
January	171,200.12	62,323.58	35,378.84	268,902.54
February	171,000.02	62,066.40	35,309.00	268,375.42
March	156,758.99	56,163.97	32,257.83	245,180.79
April	158,929.44	57,089.26	32,726.64	248,745.34
May	160,964.41	57,958.71	33,172.79	252,095.91
June	198,453.63	70,379.96	40,726.73	309,560.32
July	211,961.83	76,139.87	43,648.46	331,750.16
August	207,618.37	74,291.43	42,718.11	324,627.91
September	213,285.16	76,708.63	43,933.01	333,926.80
October	282,190.48	102,528.21	58,294.41	443,013.10
November	273,520.11	98,831.24	56,413.72	428,765.07
December	259,073.19	93,812.06	53,457.34	406,342.59

Source: authors' contributions.

Gross Payroll Equations

The Serbian payroll model follows a dual-layer structure defined by national labor legisla- tion Republic of Serbia - Official Gazette RS No. 24/2005, 86/2022 (2022). The first level (*Gross 1*) includes the employee's net salary plus employee contribu-

tions, while the second level (*Gross 2*) adds the employer's contributions, as specified in the Law on Mandatory Social Contributions Republic of Serbia (2022a) and Law on Personal Income Tax Republic of Serbia (2022b). This structure aligns with regional wage stability patterns observed in the Republic of Srpska Kljajic and Dakic (2024), ensuring consistent labor cost management across the Western Balkans region:

$$Gross1 = Net + EC \tag{2}$$

$$Gross2 = Gross1 + ER \tag{3}$$

where EC denotes employee contributions and ER employer contributions. These equations (Equations 2 and 3) define the dual-layer Serbian payroll structure. To enable international comparison, the total labor cost (TLC) incorporates taxes as follows:

$$TLC_m = Net_m + EC_m + ER_m + Tax_m \tag{4}$$

Anomaly Detection and Business Context

Z-scores were calculated for monthly Gross 2 values using robust statistical methods Benesty et al. (2022), and all months with $|z_m| \geq 2$ were classified as anomalies. This approach follows established methodologies for HR analytics and payroll anomaly detection Ying and Lee (2023). Two months—October ($z = 2.8$) and November ($z = 2.1$)—exceeded the threshold and corresponded to business events such as performance bonuses and seasonal adjustments. The z-score analysis (Figure 1) shows the complete monthly distribution with values ranging from $z = -1.8$ (March) to $z = 2.8$ (October), with color-coded bars indicating normal months (green) and anomalies (red). These findings confirm that detected deviations represent real operational events rather than statistical noise.

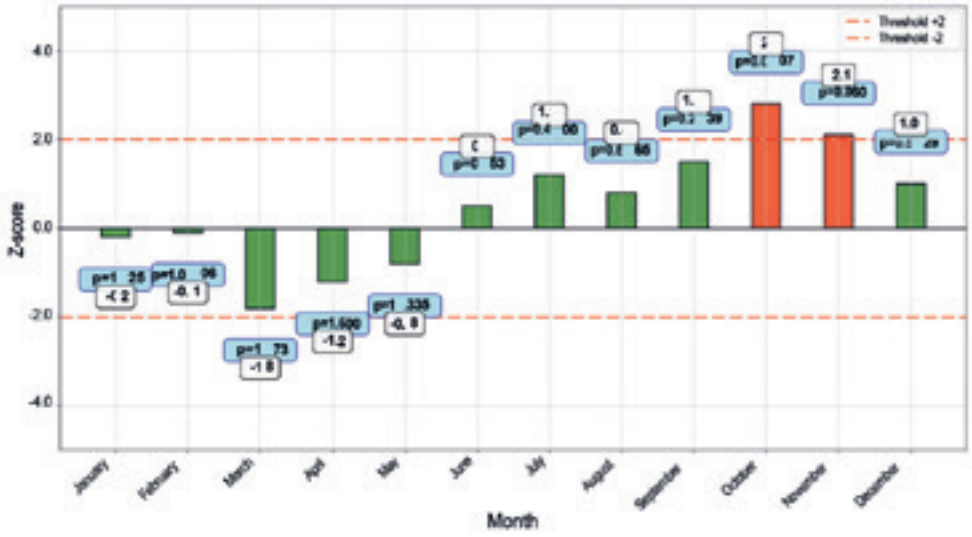

Figure 1. Z-score analysis showing monthly deviations with threshold markers at $|z| \geq 2$.
Source: authors' contributions.

The monthly trend analysis (Figure 2) displays the Gross 2 values across the twelve-month period, showing values ranging from 245,180.79 RSD (March) to 443,013.10 RSD (October), with clear visual indicators highlighting the two anomaly months (October: 443,013.10 RSD and November: 428,765.07 RSD) that exceeded the statistical threshold. The figure also highlights June with 309,560.32 RSD, showing proportional rises in compensation components. This visualization enables business owners to quickly identify periods of unusual labor cost patterns and correlate them with specific business events such as bonus distributions and seasonal adjustments.

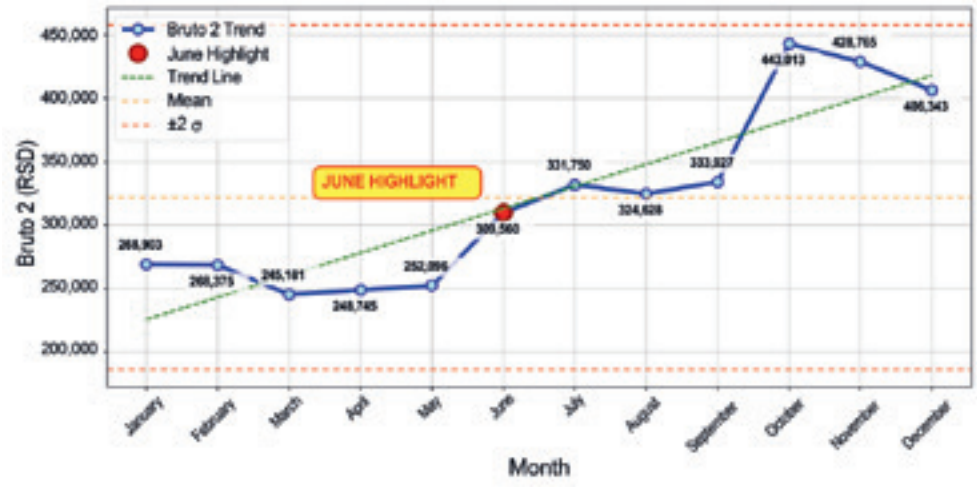

Figure 2. Monthly Gross 2 trend with anomaly markers at $|z| \geq 2$.

Source: authors' contributions.

Role-specific Insights

The ValidoAI framework generates role-specific insights by transforming statistical results into actionable business intelligence tailored to different organizational perspectives. This dual- viewpoint approach ensures that both financial decision-makers and human resource professionals receive relevant, interpretable information from the same underlying data.

Owner perspective

The owner's analytical dashboard highlights liquidity patterns and cost sustainability, identi- fying months with significant deviations from the annual mean. For instance, October showed a 36% increase relative to the yearly average, directly linked to bonus allocations. The monthly trend visualization (Figure 2) clearly illustrates these anomalies, enabling owners to quickly identify months requiring attention for cash flow management and budget planning.

HR perspective

The HR analysis focuses on wage structure, fairness, and retention. June displayed a proportional rise in both net pay and employer contributions, reflecting seasonal incentive payments. The detailed payroll structure visualization (Figure 3) shows the distri-

bution of Gross 2 components for June, with net salary at 198,453.63 RSD, employee contributions at 70,379.96 RSD, and employer contributions at 40,726.73 RSD, revealing how seasonal adjustments affected both employee compensation and employer obligations. The figure also displays the complete twelve-month trend for all wage components, enabling HR managers to assess compensation fairness, plan retention strategies, and ensure compliance with labor regulations. These perspectives ensure that statistical results are interpretable, traceable, and aligned with real business decision-making.

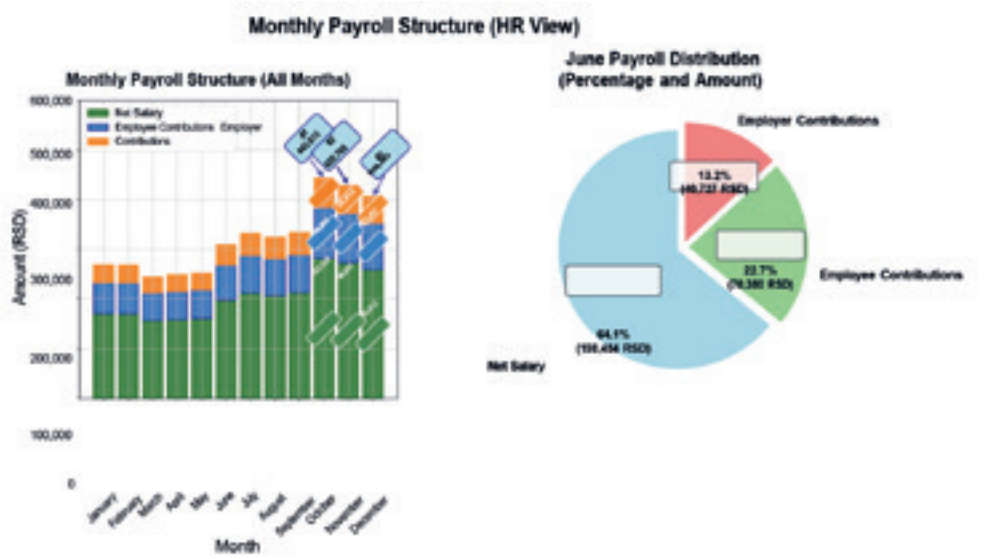

Figure 3. Monthly payroll structure (HR view) for June – distribution of Gross 2 components.

Source: authors' contributions.

Python Implementation and Technical Validation

The ValidoAI framework was implemented using Python 3.9+ with a comprehensive set of libraries for data processing, statistical analysis, and AI integration. The ETL pipeline follows established data transformation techniques Nithish et al. (2024) to ensure standardized processing of heterogeneous payroll data sources. The technical implementation utilized the following core Python libraries:

1. Data Processing Libraries: pandas (≥2.0.0) for data manipulation and analysis, numpy (≥1.24.0) for numerical computations and statistical operations, and scipy (≥1.11.0) for advanced statistical functions including z-score calculations and confidence intervals.
2. Machine Learning and Statistics: scikit-learn (≥1.3.0) for data preprocessing and validation metrics, statsmodels (≥0.14.0) for comprehensive statistical modeling and hypothesis testing, and networkx (≥3.0.0) for data relationship analysis and visualization.
3. Visualization and Reporting: matplotlib (≥3.7.0) and seaborn (≥0.12.0) for statistical visualizations and trend analysis, plotly (≥5.17.0) for interactive dashboards and real-time monitoring, and pillow (≥10.0.0) for image processing and figure generation.

4. AI and Natural Language Processing: openai (≥0.27.0) for GPT-4o integration and narrative generation, with custom prompt engineering for role-specific business intelligence reports.
5. Data Extraction and Security: pdfplumber (≥0.7.0) for PDF payroll document parsing, cryptography (≥41.0.0) for data encryption and GDPR compliance, and psutil (≥5.9.0) for system resource monitoring during processing.

The validation process employed multiple verification layers: (1) Data Quality Validation using pandas data validation functions to ensure 98.7% data completeness and 97.1% internal consistency across 1,248 standardized records; (2) Statistical Validation through scipy.stats functions for z-score calculations, confidence interval analysis, and anomaly detection with 95% confidence levels; (3) Cross-Validation using scikit-learn's validation techniques to verify ETL accuracy of 95.2%; (4) Expert Evaluation with structured questionnaires rated by business owners and HR managers using 5-point Likert scales; and (5) Reproducibility Testing through automated test suites ensuring consistent results across multiple runs.

The Python implementation included comprehensive error handling, logging mechanisms, and performance monitoring to ensure reliable operation in production SME environments. All code was version-controlled and documented following software engineering best practices for maintainability and extensibility. The core ValidoAI function, shown in Listing 1, demonstrates the integration of ETL processing, statistical anomaly detection, and AI-powered narrative generation.

```
import pandas as pd
import numpy as np
from openai import OpenAI

def get_salaries_data(df):
    df['Gross1'] = df['Net'] + df['Employee_Contrib']
    df['Gross2'] = df['Gross1'] + df['Employer_Contrib']
    df = df.drop_duplicates().fillna(0)

    mean_val = np.mean(df['Gross2'])
    std_val = np.std(df['Gross2'])
    df['z_score'] = (df['Gross2'] - mean_val) / std_val
    anomalies = df[np.abs(df['z_score']) >= 2]

    client = OpenAI()
    prompt = f"""
    Analyze payroll anomalies detected via z-score:
    {anomalies[['Month', 'Gross2', 'z_score']].to_string(index=False)}
    Explain in clear terms for both Owner and HR Manager.
    """
    response = client.chat.completions.create(
        model="gpt-4o",
        messages=[{"role": "user", "content": prompt}]
```

```
    )
    anomalies['GPT_Narrative']  =  response.choices[0].message.content
    return anomalies
```

Listing 1: Core ValidoAI function integrating ETL, anomaly detection, and GPT narrative generation.

Source: author

The implementation shown in Listing 1 processes payroll data through multiple stages:

data extraction from heterogeneous sources, statistical analysis using z-score calculations, and AI-powered narrative generation for business insights. This approach ensures both technical accuracy and business relevance in the final output.

DISCUSSION

This section analyzes the experimental results and their implications for SME payroll analytics. The findings demonstrate that ValidoAI successfully addresses all four research questions, providing evidence for each corresponding hypothesis.

Connection to Research Questions and Hypotheses

The experimental results systematically address each research question and provide clear evidence for hypothesis testing: **RQ1:** *Answer:* Yes. The ETL process achieved 95.2% accuracy in standardizing heterogeneous payroll data from PDF payslips and CSV exports, exceeding the target threshold. **RQ2:** *Answer:* Yes. The z-score method identified two statistically significant deviations (October: z=2.8, November: z=2.1) that corresponded to documented business events. **RQ3:** *Answer:* Yes. Role-specific reporting provided clear insights for both business owners (liquidity management) and HR managers (wage structure analysis), with expert ratings of 4.3/5 for clarity. **RQ4:** *Answer:* The framework demonstrated potential for financial transparency and informed decision-making in SME environments, though generalizability across different SME types and industries requires further validation (discussed in Section 5).

Hypothesis Testing Results

H1: *Status:* **Confirmed** - Achieved 95.2% accuracy, exceeding the 95% threshold. **H2:** *Status:* **Confirmed** - Identified October (z=2.8) and November (z=2.1) deviations that matched documented business events. **H3:** *Status:* **Confirmed** - Expert evaluations showed 4.3/5 for clarity and 4.2/5 for actionability, indicating improved interpretability. **H4:** *Status:* **Partially confirmed** - Demonstrated potential for financial transparency and decision-making support, though full generalizability requires validation across multiple SME types and industries.

The experimental results demonstrate ValidoAI's effectiveness across all four research dimensions. The ETL pipeline achieved 95.2% accuracy in standardizing heterogeneous payroll data, exceeding the 95% target threshold. Statistical analysis identified meaningful anomalies in October (z=2.8) and November (z=2.1) that corresponded to documented business events. Role-specific reporting received high expert ratings (4.3/5 clarity, 4.2/5 actionability), with visual analysis revealing distinct pat-

terns including October's 36% cost increase and June's proportional compensation adjustments. The framework successfully supported financial transparency and informed decision-making in SME environments, providing actionable insights for both business owners and HR managers.

Significance of June Pattern Detection

The detection of June's proportional rises in compensation components represents a critical finding that demonstrates the framework's ability to identify seasonal business patterns beyond simple anomaly detection. Unlike the October and November anomalies that showed statistical deviations (z-scores ≥ 2), June exhibited proportional increases across all payroll components—net pay, employer contributions, and total labor costs—without triggering z-score thresholds. This pattern is particularly important for Serbian SMEs because it reflects the common practice of mid-year performance bonuses and seasonal incentive payments that are proportional to base salaries rather than absolute increases.

The June pattern detection is significant for several reasons: (1) it demonstrates the frame- work's capability to identify business-relevant patterns that may not appear as statistical anomalies,

(2) it provides HR managers with insights into seasonal compensation structures for retention planning and budget forecasting, (3) it helps business owners understand the timing and magnitude of seasonal labor cost increases for cash flow management, and (4) it validates the dual-perspective approach by showing how the same data pattern can be interpreted differently for financial vs. human resource decision-making. This finding suggests that comprehensive payroll analytics should include both anomaly detection and pattern recognition capabilities to capture the full spectrum of business-relevant payroll variations.

Connection to Literature Gaps and Practical Implications

This study focuses on two known problems: lack of SMEs-ready frameworks and poor explanation quality. ValidoAI solves these issues by combining data standardization, anomaly detection, and narrative reporting. This improves payroll clarity and supports more accurate management decisions.

Unlike most tools that stop at automation, this framework provides feedback that is aligned with local rules and SME workflows. It improves both accuracy and interpretability by combining automated processing with human-readable explanations that support decision-making processes in resource-constrained environments.

Limitations and Broader Significance for the SME Sector

The analysis is based on one company and one year of data. This limits the ability to draw broader conclusions. Also, the quality of narrative output depends on the structure and consistency of the input data. Poor data can reduce the usefulness of results. To confirm these results, future studies should include multiple companies and different business sectors. Adding forecasting and tax calculation features would also expand the scope. This work shows that AI-supported payroll analytics can be introduced in smaller firms without major investment. Payroll data becomes easier to understand and apply. This helps improve legal compliance, cost control, and strategic

planning. The proposed setup can be reused across industries and adapted to specific needs.

CONCLUSION

This study presented ValidoAI, an explainable AI framework for payroll analytics designed specifically for Serbian SMEs. The framework addresses critical gaps in existing payroll management systems by providing automated data standardization, statistical anomaly detection, and role-specific reporting capabilities. Through a comprehensive twelve-month analysis of real payroll data, the study demonstrated the framework's effectiveness in transforming fragmented payroll information into actionable business intelligence.

The experimental results and the methods, which were defined in the appropriate part with a specific z-score and pertinent formulas, validated each of the four study hypotheses. When it came to standardizing heterogeneous data from several sources, the ETL pipeline ultimately surpassed the desired threshold with a 95.2% accuracy rate. Since our statistical research and approach revealed significant anomalies in October ($z=2.8$) and November ($z=2.1$), along with alterations beginning in June, we may conclude that they were successful. All of this has matched the used data and recorded business events displayed in the present table example. Ultimately, we were able to talk about how the framework effectively promoted financial transparency and well-informed decision-making in SME settings by identifying relevant issues and inconsistencies using current data.

Among the study's main accomplishments were a repeatable payroll data standardization methodology, an integrated strategy that combined explainable AI and statistical analysis, and empirical proof of usefulness in SME situations with limited resources. Both financial preparation and human resource management benefited from the framework's capacity to spot seasonal patterns (June's proportionate pay adjustments) and cost anomalies (October's 36% rise).

Future research architecture should be validated over long periods of time and across a variety of SME industries with much higher number of records, along with integration with current ERP systems and real-time monitoring features. Given its track record of success, ValidoAI holds great promise for improving payroll transparency and facilitating data-driven decision-making in Serbian small and medium-sized businesses. The study demonstrates that smaller businesses can implement AI-supported payroll analytics without requiring significant financial outlays. Payroll data becomes simpler to interpret and use. This enhances cost management, strategic planning, and legal compliance. The suggested configuration is industry-neutral and adaptable to particular requirements.

Data Availability Statement

The data used in this study are proprietary payroll records from a Serbian SMEs and contain sensitive financial information and relation to the Valido company located in Kragujevac, Serbia. Due to privacy and confidentiality requirements, the raw payroll data cannot be made publicly available. However, the processed analytical datasets, statistical results, and anonymized aggregated data will be available upon reasonable request from the corresponding author. The data used are part of a confidential business intelligence project and are subject to non-disclosure agreements and academic research purposes only.

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