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ANALYSIS OF MEETING EARLY CHILDHOOD EDUCATION RESOURCE NEEDS THROUGH MONTE CARLO SIMULATION

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ABSTRACT

Accurate resource planning is a critical challenge in managing Early Childhood Education (ECE) institutions, especially in semi-rural areas facing budget constraints and fluctuating student enrollment. This study aims to apply the Monte Carlo Simulation method as a quantitative approach to predict resource needs at PAUD Ceria Mojokerto over one academic year. The research focuses on three main components: teaching staff, stationery supplies, and classroom space. Historical data from the past five years were used to build probability distributions and model student enrollment and attendance rate uncertainties. PAUD Ceria Mojokerto was chosen as a case study due to its representativeness of typical conditions in semi-rural ECE settings. The simulation results indicate that the required number of teaching staff ranges from 2 to 5, stationery supplies range from 103 to 496 units, and classrooms range from 2 to 4 per academic year. These findings highlight that the approach offers more flexible and realistic estimates than conventional deterministic methods. Therefore, ECE administrators are encouraged to integrate quantitative methods such as Monte Carlo Simulation into their operational planning to enhance efficiency, resilience to student population dynamics, and data-driven decision-making. This research contributes to developing data-driven educational planning practices, particularly in resource-limited settings.

Keywords*: Monte Carlo, Resources, Early Childhood Education*

A. INTRODUCTION

Behind the cheerful scenes of children playing and learning at Early Childhood Education (ECE) institutions lie significant challenges faced by administrators: how to ensure that all necessary resources are available in a timely and adequate manner (Najib & Roza, 2022; Rinta et al., 2022; Sepriano & Susanti, 2021). Early Childhood Education (ECE) plays a crucial role in the holistic development of children, making it essential to carefully and systematically plan facilities, classrooms, and teaching staff (Dwika, 2022; Asiah et al., 2024; Hairiyah, 2024). ECE institutions in under-resourced areas must operate effectively and efficiently despite facing difficulties in planning for sufficient educators, learning materials, and classroom space (Eka et al., 2022; Rohiyatun & Najwa, 2021; Suteki

& Sulistyowati, 2024).

Errors in planning often result in disrupted learning processes, budget inefficiencies, or mismatches between needs and available resources (Aprilyani & Anwar, 2021). Resource planning in ECE institutions is often based on administrators' experience or subjective estimates (Rohiyatun & Najwa, 2021; Susanti, 2018). The application of the Monte Carlo Simulation method in ECE remains rare, even though this method can accurately help plan for resources such as equipment, teaching staff, and daily needs while minimizing operational risks (Sepriano & Susanti, 2021).

Monte Carlo Simulation (MC) is widely used in business practice for sensitivity analysis, risk quantification, and prediction. It addresses the limitations of mathematical models and manages precision and error through proper sampling techniques (Nilakantan, 2015). It estimates uncertainty in process models and the probability of failure in engineering systems. It has high computational costs that can be reduced using support vector machines and Metropolis-Hastings algorithms (Lee & Kim, 2020).

Monte Carlo Simulation is applied in finance, risk management, and economics, and is well-suited for practitioners and researchers. It is also a supplement to advanced-level education (Brandimarte, 2014). Modern Monte Carlo methods include variance reduction techniques, Monte Carlo optimization, rare event estimation, and stochastic programming methods using the latest algorithms, supported by exercises and application examples (Rubinstein & Kroese, 2016). Monte Carlo simulations and their applications in research are designed to help simplify complex statistical concepts practically (Sigal & Philipchalmers, 2016).

Monte Carlo Simulation is effective in education due to its accessibility, cross-platform compatibility, and support for understanding complex dynamic systems (Oh et al., 2015). KBR used Monte Carlo Simulation to model potential outcomes in the paper industry process, aiding in more accurate operational risk analysis, cost efficiency, and process variability (Nichols, 2020). Monte Carlo Simulation uses computational algorithms to estimate probability distributions accurately, making it suitable for complex systems and widely applied in science, engineering, business, and space exploration (Rezvani & Bolduc, 2014).

Monte Carlo Simulation offers an alternative approach when analytical calculation is complex. It utilizes random numbers and statistics to accurately assess data uncertainty with modern computational power (Signoret & Leroy, 2021). Monte Carlo is a theoretically robust method that functions as an ideal experiment based on computation and probability (Dapor, 2023). Although widely used in estimating and developing imaging detectors, high computation time remains a challenge, prompting AI-based approaches to accelerate the process (Sarrut et al., 2021).

Based on this background, this study aims to apply the Monte Carlo Simulation method to predict resource needs at the Ceria Mojokerta ECE institution over an academic year. This research mainly analyzes fluctuations in key variables, namely the number of active students, daily attendance rates, and daily logistical needs. The results of this study are expected to contribute to the development of data-driven ECE management and encourage the use of quantitative methods in strategic decision-making within the early childhood education sector.

B. RESEARCH METHOD

This study employs a quantitative descriptive approach using the Monte Carlo Simulation method to predict resource needs at Ceria Mojokerto Early Childhood Education (ECE) institution over one academic year. This approach was chosen because it can provide a systematic and measurable overview of the dynamic, daily fluctuations in resource demand. The Monte Carlo Simulation method is used to estimate the needs for stationery, food, and learning materials, considering daily variations in student attendance and individual consumption. This technique generates thousands of random simulations based on probability distributions derived from historical data collected over the past five years, enabling more realistic and adaptive estimates in the face of uncertainty. The strength of this method lies in its ability to capture real-world fluctuations that deterministic approaches cannot account for. The subject of this study is Ceria Mojokerto ECE, located in a semi-rural area and operating for more than five years. This institution was selected purposively based on criteria such as completeness of historical data, significant student dynamics, and openness to innovative approaches. Data were collected through document analysis, structured interviews, and direct observation and validated through triangulation. Simulation results were analyzed descriptively using basic statistics and graphical visualization to identify demand patterns and potential resource shortages or surpluses risks.

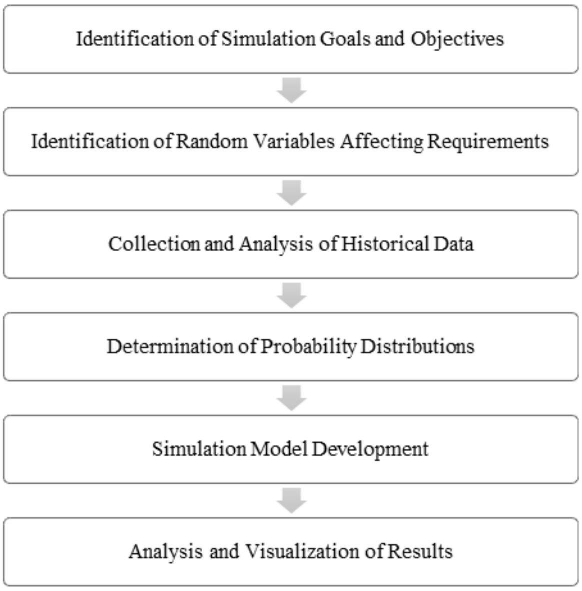


Figure 1. Framework For Predicting Resource Requirements

C. RESULTS AND DISCUSSION

Based on the Monte Carlo simulation results, a prediction of resource requirements at the early childhood education center (ECE) for one academic year has been obtained. The simulation used historical data on the number of students over the past five years, which was then analyzed to determine fluctuation patterns and probability distributions. With 1,000 simulation iterations, an overview of the variation in the needs for teaching staff, educational supplies, and classroom space based on the possible number of students admitted each month was generated. These results indicate a range of resource needs that PAUD must prepare for to face the uncertainty in student enrollment numbers.

Table 1. Student Enrollment Data

Academic Year	Number of Students	Average Attendance	Number of Teachers
2020/2021	25	88%	2
2021/2022	22	91%	2
2022/2023	28	85%	3
2023/2024	30	93%	3

The Monte Carlo simulation was conducted based on historical data on the number of teachers from the 2020/2021 to 2023/2024 academic years. The primary data was obtained from the institution's internal administrative records, which recorded the number of students, average attendance, and teachers each year. This data reflects actual field dynamics and is the foundation for developing a probabilistic prediction model. Using the Monte Carlo method, the uncertainty in student enrollment and teacher requirements can be modeled more realistically. In this simulation, the prediction of resource needs follows the formulas below:

Table 2. Formulas Used in the Simulation

No.	Component	Formula	Description
1	Simulated Resource Requirement	$K_i = X_i \times Y_i$	Operational needs based on several students and the per-student resource ratio.
2	Mean	$\bar{Y} = (1/n)\, \Sigma\, K_i$	Average of all simulation results.
3	Standard Deviation	$\sigma = \sqrt{[(1/(n-1))\, \Sigma\, (K_i - \bar{Y})^2]}$	Measures the spread of simulation results from the mean.
4	Predicted Number of Classrooms	[X / R]	X = number of students; R = max student-to-classroom ratio; result is rounded

			up.
5	Monte Carlo Simulation Steps	1. Randomize X and Y 2. Compute K = X × Y 3. Repeat for n iterations 4. Analyze results	Procedural steps for applying the Monte Carlo method in education planning.

The steps for determining simulation results follow the process below:

Monte Carlo Simulation Procedure

a. Define Random Variables
   - X = number of students
   - Y = resource requirement ratio per student

b. Construct the Requirement Model
   - Total resource requirement (K) is calculated as:
     $K = X \times Y$

c. Build the Probability Distribution
   - Historical data is used to form the distribution of values for X and/or Y (can be assumed as normal, triangular, or uniform distribution).
   - If X varies by year, then:
     $X \sim$ historical distribution

d. Monte Carlo Simulation Process
   Perform n iterations (e.g., 1000), with the following steps:
   - Randomly generate X_i from the historical distribution
   - Randomly generate Y_i (if required)
   - Compute the requirement using:
     $K_i = X_i \times Y_i$
   - Resulting in a set of simulated outputs:
     $K = \{K_1, K_2, K_3, \ldots, K_n\}$

e. Statistical Calculations
   After n iterations, calculate the following statistics:
   - Mean (Average Requirement):
     $\bar{Y} = (1/n)\, \Sigma\, K_i$
   - Standard Deviation:
     $\sigma = \sqrt{[(1/(n-1))\, \Sigma\, (K_i - \bar{Y})^2]}$

f. Requirement Prediction Summary
   - (1) Randomize values for X and Y
   - (2) Calculate K = X × Y
   - (3) Repeat for n iterations
   - (4) Analyze the results

1. Teacher Workforce Requirement Simulation

The simulation of teacher workforce requirements was conducted under the assumption of a normal distribution based on the available historical data. The average number of teachers over the past four academic years was calculated, and then a Monte Carlo simulation with 10,000 iterations was run to project future teacher needs. The most frequently occurring outcomes 3 and 4 indicate that, in most scenarios, the institution will require at least three active teachers to serve the enrolled students. This is relevant given the increasing trend in student numbers, particularly in the 2022/2023 and 2023/2024 academic years. Therefore, the institution needs to pay close attention to maintaining an ideal teacher-to-student ratio to uphold the quality of education. This ratio is also critical in the context of national education regulations, which set minimum standards for teacher-to-student ratios at each level of education.

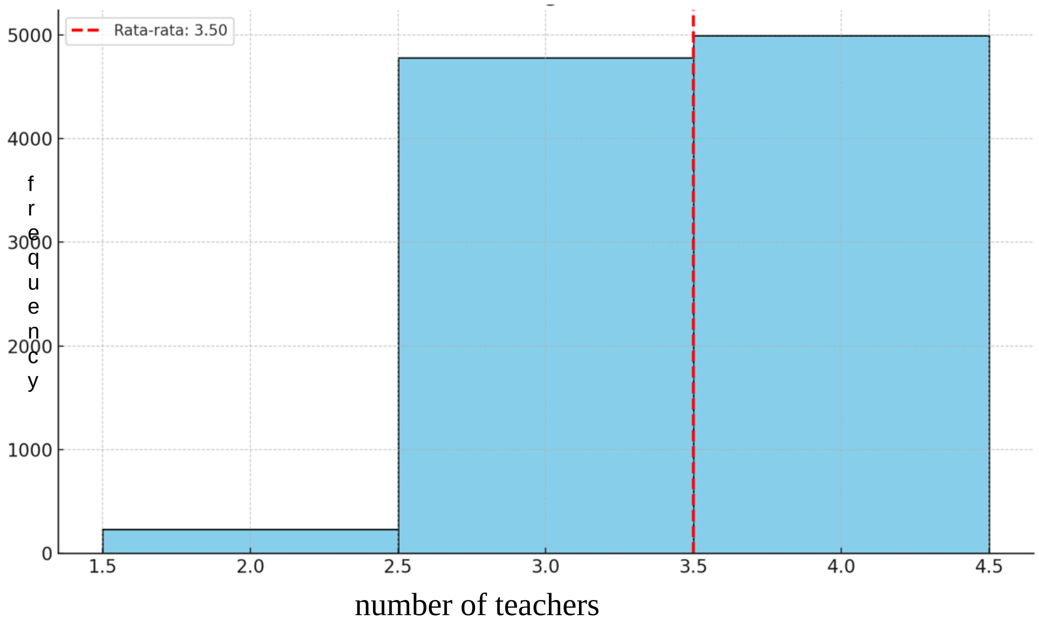


Figure 2. Distribution of Predicted Teacher Requirements

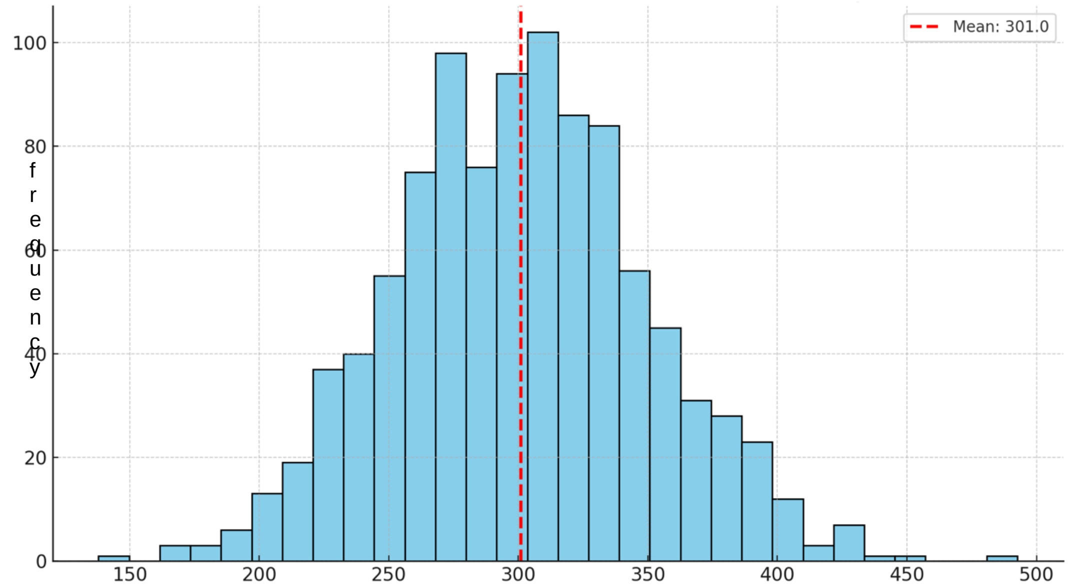
From the distribution of the simulation results in Figure 2, it can also be observed that there is a small probability of needing fewer than 3 teachers and a significant probability of needing 4 teachers. This indicates that external factors, such as surges in new student admissions or educational service expansion programs, can increase the demand for teaching staff. Therefore, educational institutions are advised not only to recruit based on the current minimum needs, but also to prepare a reserve of teaching personnel in anticipation of future student growth.

The visualization of the simulation results shows a symmetrical distribution pattern, indicating stability in teacher demand based on past data trends. The highest frequency occurs when 3 to 4 teachers are needed, reinforcing the recommendation for medium-term human resource planning. This scenario also considers natural fluctuations in student numbers, which are influenced by external factors such as demographic changes, zoning policies, and community preferences for the institution (Paramita et al., 2024; Robledo, 2013).

The simulation results indicate that the distribution of teacher demand is centered around 3.5 teachers per year, as shown by the red average line on the histogram. The relatively narrow distribution range shows that variability in teacher demand is not too large, allowing staffing planning to be conducted with relatively low uncertainty risk. This suggests that to maintain the quality of education and meet the ideal teacher-student ratio, institutions should consider a minimum of 3 to 4 teachers for each upcoming academic year.

2. Simulation of Stationery Set Needs

The simulation of the stationery set needed per student was calculated based on historical data on student enrollment over the past four years, combined with assumptions regarding stationery requirements per student. The resulting frequency distribution shows a regular pattern, with a slight right skew, indicating the possibility of higher stationery needs in specific scenarios. The total stationery requirement calculated from this simulation is approximately 301 units per year.



Total Quantity of Stationery

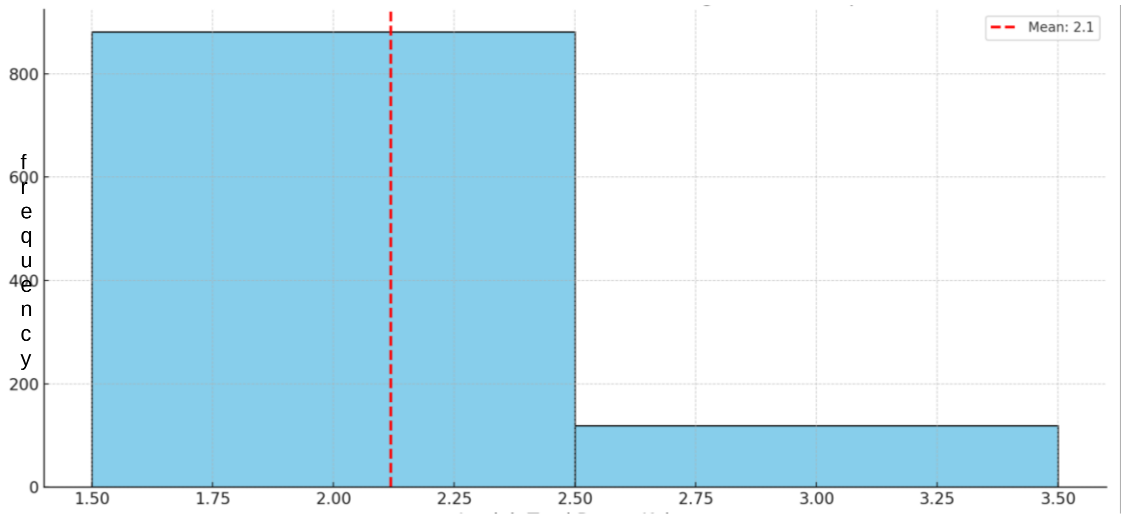
Figure 3. Simulation of Annual Stationery Set Needs

The mean requirement of 301 units, as indicated by the red dashed line on the graph, serves as the central point in the simulation distribution. This implies that under normal conditions without significant fluctuations in student numbers, educational institutions can estimate their annual stationery needs to be around this figure. However, the relatively wide spread of predicted values ranging from around 150 to nearly 500 units indicates a level of variation that must be considered in procurement planning. The highest frequency from the simulation results is concentrated in the 280 to 320 units, suggesting that, in most cases, annual needs will fall within this range. In practice, institutional management should provide stationery in quantities exceeding the average to anticipate student surges or other unforeseen needs that may arise during the academic year.

Furthermore, the distribution results show a possibility of significantly lower needs, namely below 250 units. Although the frequency is minor, such a scenario may occur due to a decline in student numbers caused by external factors such as student relocation, natural disasters, or changes in government policy. Therefore, institutional management needs to develop an adaptive monitoring system to track changes in student numbers throughout the academic year (Bararah, 2020; Quinn, 2013; Taran & Kebu, 2023).

3. Classroom Space Requirement Simulation

The following simulation chart illustrates the predicted number of classrooms Ceria Mojokerto ECE needs to accommodate student growth over one academic year. The frequency distribution shows that most simulations require around two classrooms, with an average demand of 2.1 classrooms, as indicated by the red dashed line. This outcome suggests that, under normal operations, a minimum of two active classrooms should be made available each year.



Total Number of Classrooms

Figure 4. Classroom Requirement Simulation

Most frequencies are concentrated within the range of 1.5 to 2.5 classrooms, indicating that in over 80% of simulations, the classroom demand does not exceed two. This is a strong basis for the institution to prioritize providing or optimizing two classrooms as part of its annual planning. Having two classrooms available also provides flexibility in learning arrangements, whether for grouping students by age or accommodating different learning programs (Agustriani et al., 2022; Kresnawaty, 2024; Susanti, 2018).

However, some simulation results show a need to approach or slightly exceed three classrooms. Although the frequency of such scenarios is significantly lower than the need for two classrooms, they cannot be ignored. These scenarios imply that in cases of student growth exceeding the average prediction, Ceria Mojokerto ECE must be prepared with contingency plans, such as utilizing multi-purpose rooms, rotating class schedules, or medium-term physical expansion strategies (Iftitah & Yuhandri, 2020; Simangunsong, 2023).

The average classroom demand of 2.1 indicates that the institution should consider flexible space management. This may involve implementing shift-based learning schedules or reorganizing classroom capacity for optimal use. Such capacity management is crucial for maintaining the quality of education, particularly to ensure that the number of students per class remains ideal and complies with national education regulations (Wulandari & Wulandari, 2023). The concentration of demand around two classrooms also reflects stability in student enrollment growth. There is no indication of a significant spike that would necessitate the rapid construction of additional classrooms. Therefore, the institution can allocate development budgets in a more planned and gradual manner, avoiding resource waste due to overcapacity planning.

D. CONCLUSION

Based on the Monte Carlo simulation results, this study demonstrates that a probabilistic approach can provide a more realistic predictive overview of resource needs at Ceria Mojokerto ECE. By utilizing historical data and accounting for random variables such as fluctuations in student enrollment, the estimated needs vary by real-world dynamics. The simulation results indicate that stationery needs range from 103 to 496 units, teaching staff from 2 to 5 individuals, and classrooms from 2 to 4 rooms. This range is crucial as a foundation for flexible and risk-based planning. Compared to the more static deterministic approach, this method is more adaptive and contextual, especially in early childhood education environments with limited resources. The implementation of the Monte Carlo simulation is shown to be both practical and relevant in supporting efficient management at ECE, particularly in semi-rural contexts. These findings are beneficial not only for ECE administrators but also for stakeholders such as village governments or community partners in designing data-driven policies. However, since this study is limited to one institution, the results should be generalized cautiously. Therefore, further research with a broader scope and training for ECE managers in applying this model is recommended for sustainable strategic management.

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AUTHOR CONTRIBUTIONS

Author 1	:	Topic design, problem formulation, fieldwork, interviews, and introduction writing.
Author 2	:	Literature review, theory building, instrument design, data triangulation
Author 3	:	Data analysis, discussion writing, theory connection, and result interpretation

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