

Forecasting Internal Labor Supply at Baganuur JSC, A Strategic Energy Hub of Mongolia: A Markov Chain Analysis

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ABSTRACT

Workforce planning and forecasting are critical for enhancing organizational performance, particularly in capital-intensive industries. This study analyzes and forecasts the internal labor supply of Baganuur JSC, a state-owned coal mining company in Mongolia, using a Markov chain model. The analysis draws on historical human resource data spanning 2005–2014, from which transition probabilities across workforce segments—including age, education level, gender, and tenure—are estimated. The findings reveal a pronounced aging trend, with a growing proportion of employees approaching retirement age, signaling a potential risk of labor shortages and loss of experienced personnel. Scenario analysis further demonstrates that variations in hiring and attrition rates significantly influence long-term workforce stability. Based on the quantitative forecasts, the study derives actionable strategic insights: by 2035, approximately 40% of the workforce is projected to be aged 50 or above, necessitating an estimated 60–80 new hires annually to sustain operational capacity. Three scenario-based HR strategy frameworks—baseline, high-attrition, and accelerated recruitment—are presented to support succession planning and human capital sustainability. The findings contribute to the limited body of quantitative workforce forecasting research in developing economies and provide data-driven decision-making tools for HR managers in Mongolia's mining sector.

Keywords: human resource management; internal labor supply; workforce planning; Markov chain model; labor forecasting; mining industry; Mongolia

INTRODUCTION

Strategic human resource management has emerged as a central concern for capital-intensive industries worldwide. In the mining sector, workforce continuity is directly tied to operational performance, safety compliance, and long-term profitability. Yet many organizations in developing economies continue to rely on informal, judgment-based approaches to workforce planning, which are widely criticized for their subjectivity and limited predictive accuracy (Taylor, 2005).

Baganuur JSC is a state-owned coal mining company and a strategic energy supplier for Mongolia's national grid. Given the capital-intensive nature of coal mining and the critical role of experienced technical personnel, effective internal labor supply forecasting is essential for the company's operational sustainability. However, like many Mongolian enterprises, Baganuur JSC has lacked a systematic, data-driven methodology for human resource planning.

The present study addresses this gap by applying a Markov chain model to historical workforce data from 2005 to 2014. Markov chain analysis is a well-established quantitative technique for modeling employee transitions across workforce states and for generating probabilistic forecasts of future workforce composition (Bartholomew et al., 1991). By extending this methodology to the context of a Mongolian state-owned enterprise, this study contributes to the limited literature on quantitative HR planning in developing economies and provides practical, decision-ready insights for HR practitioners.

The specific objectives of the study are: (1) to estimate transition probability matrices for workforce segments defined by age, education, tenure, and gender; (2) to forecast the internal labor supply structure of Baganuur

JSC up to 2050; (3) to conduct scenario analysis under varying hiring and attrition assumptions; and (4) to derive strategic HR recommendations grounded in the quantitative findings.

LITERATURE REVIEW

Workforce Forecasting and Quantitative Methods

Human resource planning and workforce forecasting have become increasingly important in modern organizational management, particularly under conditions of economic uncertainty and rapid technological change. Early studies emphasized the role of managerial judgment in workforce planning; however, such approaches have been widely criticized for their subjectivity and limited predictive accuracy (Taylor, 2005). As organizations grow in complexity, the need for quantitative and data-driven approaches has become increasingly evident.

Markov Chain Models in HR Planning

One of the most widely used quantitative methods in workforce forecasting is the Markov chain model. This approach enables the analysis of employee transitions between different states—such as job categories, age groups, or employment statuses—based on historical transition probabilities. Bartholomew et al. (1991) demonstrate that Markov models provide a structured framework for analyzing workforce dynamics and are particularly effective in manpower planning. Similarly, Vassiliou (1992) highlights their usefulness in long-term forecasting, where workforce movements can be modeled as probabilistic processes.

Subsequent research has expanded the application of Markov models by integrating them with optimization techniques and simulation methods. De Feyter (2006) shows that incorporating scenario analysis enhances the robustness of workforce forecasts under uncertainty. More recent studies have combined Markov models with machine learning and predictive analytics to improve forecasting accuracy and adaptability (Goh and Law, 2019). These hybrid approaches address a key limitation of traditional Markov models: the assumption of stationary transition probabilities.

Workforce Planning in Developing Economies and the Mining Sector

Despite these methodological advances, the application of quantitative workforce forecasting remains limited in developing economies and capital-intensive sectors such as mining. Many organizations continue to rely on traditional planning approaches, resulting in inefficiencies in labor allocation and elevated risks of workforce imbalances. In particular, aging workforce structures and high attrition rates present significant challenges to long-term human resource sustainability (Tseveenjav et al., 2012).

In Mongolia, empirical research applying advanced quantitative models to workforce planning remains scarce. Existing studies tend to focus on descriptive analysis rather than predictive modeling, limiting their practical value for strategic decision-making (Tsetsegmaa, 2009; Sambalkhundav, 2000). This gap underscores the need for applying robust analytical methods—such as Markov chain models—to better understand workforce dynamics and support HR planning in Mongolia's resource extraction sector.

METHODOLOGY

Data

This study uses longitudinal human resource records from Baganuur JSC covering the period 2005–2014. The dataset includes annual workforce snapshots disaggregated by age group (20–30, 31–40, 41–50, and 51+), education level (higher, secondary, and specialized secondary), years of service, and gender. Employee transition events—including internal group movements, new hires, and terminations—were extracted for each annual interval to construct the empirical transition matrices.

Markov Chain Framework

Let $\{X_t, t = 2005, 2006, \dots, 2014\}$ be a discrete-time stochastic process where X_t denotes the workforce state vector at time t . The process satisfies the Markov property if:

$$P(X_t = j \mid X_0 = i_0, X_1 = i_1, \dots, X_{t-1} = i) = P(X_t = j \mid X_{t-1} = i)$$

That is, the future state depends only on the current state, not on the history of states. The workforce at Baganuur JSC satisfies this property because: (1) the number of employees in a given year is determined solely by the number in the previous year; and (2) a fixed proportion of employees transitions between groups after each unit period.

Employees are divided into k groups based on a given characteristic (e.g., age). Let $n_i(t)$ denote the number of employees in group i at time t . The transition probability matrix Q is estimated from the observed data, where q_{ij} represents the probability that an employee in group i at time t will be in group j at time $t+1$. The vector of group sizes at time $t+1$ is given by: $N(t+1) = N(t) \cdot Q + R(t)$, where $R(t)$ captures new recruitment.

Scenario Design

To address the reviewer’s recommendation and to provide decision-relevant insights, three scenarios were constructed:

Scenario 1 – Baseline: Transition probabilities and recruitment rates remain at their 2005–2014 averages. This scenario projects the workforce structure assuming no policy change.

Scenario 2 – High Attrition: The termination rate for the 51+ age group is increased by 50% to simulate accelerated retirements, reflecting a potential policy incentivizing early retirement.

Scenario 3 – Accelerated Recruitment: The proportion of new hires in the 20–30 age group is increased to 0.70 (from the observed 0.47), simulating a youth-focused recruitment strategy.

RESULTS

Transition Probability Matrices

Based on historical HR data, the following transition probability parameters were estimated for each age group. Table 1 shows the termination (p), retention (a), and transition probabilities ($1-p-a$) for each age cohort.

Table 1. Transition Parameters by Age Group

Parameter	20–30	31–40	41–50	51+
Termination (p)	0.02	0.04	0.03	0.17
Retention (a)	0.88	0.86	0.87	0.83
Transition ($1-p-a$)	0.10	0.10	0.10	0.00

The full transition probability matrix Q , which incorporates both retention and replacement hiring patterns, is presented in Table 2.

Table 2. Transition Probability Matrix Q (Age Groups)

From \ To	20–30	31–40	41–50	51+
20–30	0.90	0.10	0.00	0.00
31–40	0.03	0.87	0.10	0.00
41–50	0.01	0.01	0.88	0.10
51+	0.05	0.03	0.07	0.85

The recruitment age distribution R of newly hired employees was empirically estimated as: $R = [0.469, 0.386, 0.109, 0.036]$, indicating that the majority of new hires are drawn from the 20–30 age cohort.

Age Structure Trend Forecast

Using the baseline scenario (Scenario 1), the Markov chain model projects the age structure of Baganuur JSC’s workforce through 2050. Key findings are summarized below:

- The proportion of employees aged 20–30 is projected to decline steadily from approximately 29% in 2014 to 18% by 2030 and 14% by 2050 under baseline assumptions.
- The proportion aged 51 or above is projected to rise from 22% in 2014 to an estimated 40% by 2035, and to approximately 46% by 2050.
- Under Scenario 2 (high attrition), the 51+ share peaks earlier (approximately 2032) but declines thereafter as accelerated retirements open vacancies for younger cohorts.
- Under Scenario 3 (accelerated recruitment), the 20–30 cohort stabilizes at approximately 24% by 2030, partially reversing the aging trend.

Educational Background Structure Trend

Baganuur JSC employees were categorized into three education groups: higher education, secondary education, and specialized secondary education. Markov chain projections indicate that the share of employees with higher education is expected to grow modestly over the forecast horizon, driven primarily by the educational composition of new hires. The share of specialized secondary education holders is projected to decline gradually as older cohorts retire. These trends carry implications for training program design and succession planning for technical roles.

Years of Service Structure Trend

The tenure distribution analysis reveals a bimodal pattern: a growing cluster of employees with 20 or more years of service (reflecting the aging workforce) and an increasing share of relatively new employees with fewer than five years of service. This bifurcation underscores the urgency of structured knowledge transfer programs to prevent the loss of institutional expertise as long-tenured employees retire.

Gender Structure Trend

The gender structure analysis indicates that the male-to-female ratio in the workforce has remained relatively stable over the observed period. Markov chain projections suggest this ratio will persist under baseline hiring assumptions. However, targeted diversity hiring policies could substantially alter the composition within a decade, given the relatively high annual turnover in entry-level positions.

Strategic Insights and Scenario Analysis

Quantitative Decision Benchmarks

The Markov chain forecasts yield several concrete, decision-ready benchmarks for HR strategy at Baganuur JSC:

Table 3. Key Strategic Benchmarks Derived from Markov Chain Forecasts

Indicator	Projected Value	Strategic Implication
Share of workforce aged 50+ by 2035 (Baseline)	~40%	Imminent succession risk; expedite leadership pipeline
Annual hires needed to maintain headcount (Baseline)	60–80 per year	Minimum annual recruitment target for HR planning
20–30 share decline by 2030 vs. 2014 (Baseline)	–11 pp	Youth attraction strategy required
Impact of Scenario 3 on 20–30 share by 2030	+6 pp vs. baseline	Targeted recruitment measurably reverses aging trend

Scenario Comparison

To provide a robust decision-support framework, a predictive machine learning model was implemented to simulate workforce trajectories under varying policy constraints. This simulation moves beyond static reporting to dynamic forecasting, allowing for 'what-if' analysis of strategic HR interventions.

Table 4 summarizes the projected age composition under the three scenarios in 2030 and 2040, illustrating the sensitivity of the workforce structure to HR policy choices.

Table 4. Projected Age Group Shares Under Three Scenarios (%)

Scenario / Year	20–30	31–40	41–50	51+
S1 Baseline – 2030	18	21	21	40
S1 Baseline – 2040	15	18	21	46
S2 High Attrition – 2030	20	22	22	36
S2 High Attrition – 2040	18	20	22	40
S3 Accel. Recruitment – 2030	24	22	21	33
S3 Accel. Recruitment – 2040	22	21	21	36

Note: Values are model projections based on estimated transition probabilities; figures are rounded to the nearest integer.

DISCUSSION AND HR STRATEGY RECOMMENDATIONS

Interpretation of Findings

The results confirm the hypothesis that Baganuur JSC faces a structural aging challenge that will intensify over the coming decades without deliberate policy intervention. The high retention probability for the 51+ cohort ($a = 0.83$) combined with the elevated termination rate ($p = 0.17$) indicates a large, relatively stable senior workforce that will transition to retirement in successive waves. This pattern is consistent with broader trends

observed in post-Soviet industrial enterprises, where workforce structures reflect the hiring surges of the 1980s and 1990s (Sambalkhundav, 2000).

The scenario analysis reveals that the choice of recruitment strategy has a measurable and relatively rapid effect on workforce composition. Scenario 3 demonstrates that shifting the recruitment age distribution toward younger cohorts can reduce the projected 51+ share by approximately 7 percentage points by 2030 relative to the baseline, underscoring the leverage that HR managers hold through targeted hiring policies.

HR Strategy Recommendations

Based on the quantitative forecasts, the following strategic recommendations are proposed for Baganuur JSC's human resource management:

1. Establish an Annual Recruitment Target. The model projects a minimum requirement of 60–80 new hires per year under baseline conditions to maintain headcount. HR planning cycles should be anchored to this benchmark, with targets adjusted annually as updated transition data become available.

2. Prioritize Youth-Focused Recruitment. Given that the 20–30 cohort is the primary source of long-term workforce renewal, recruitment campaigns should be directed at universities, vocational training institutes, and graduate programs relevant to mining engineering and operations management. Internship and apprenticeship pipelines should be formalized. This recommendation aligns with Oyu Tolgoi's successful Graduate Development Programme (YPG), which bridges the gap between academic theory and operational practice through structured internships and guaranteed career pathways.

3. Implement a Structured Succession Planning Program. With approximately 40% of the workforce projected to reach the 51+ bracket by 2035, succession planning for critical technical and managerial roles must begin immediately. Each key position should have an identified successor with a documented development plan.

4. Design Knowledge Transfer Mechanisms. The high tenure concentration in the 51+ cohort represents significant institutional capital. Mentoring programs pairing experienced employees with younger counterparts, as well as structured documentation of tacit operational knowledge, should be established before large-scale retirements materialize. This approach adopts Erdenet Mining Corporation's 'Master-Apprentice' (Mentorship) framework, where senior expertise is institutionalized through digital knowledge repositories and structured mentorship KPIs.

5. Consider Selective Retention Incentives for Specialized Roles. Under the high-attrition scenario, critical technical roles (e.g., mine engineers, safety specialists) may be vacated faster than they can be filled. Targeted retention incentives (flexible work arrangements, phased retirement, consulting contracts) for employees in hard-to-replace positions should be evaluated.

6. Institutionalize Annual Markov Model Updates. The predictive power of the Markov chain model increases as additional years of transition data are incorporated. Baganuur JSC should designate an HR analytics function responsible for updating the transition matrices annually, revising scenarios, and reporting deviations from projected workforce trajectories to senior management.

By integrating these global and local best practices with the quantitative results of the Markov model, Baganuur JSC can transition from reactive personnel management to a proactive, data-driven workforce strategy. This alignment ensures that the company remains competitive in attracting young talent while strategically managing the risks associated with its aging workforce structure.

Limitations

This study has several limitations that should be acknowledged. First, the Markov model assumes stationary transition probabilities over the forecast horizon, which may not hold as organizational and macroeconomic conditions change. Second, the data cover the period 2005–2014; more recent data, if available, would

improve forecast accuracy and relevance. Third, the model does not account for external labor market dynamics, such as competition for skilled workers or changes in education and training supply. Future research should explore non-stationary Markov models and hybrid approaches that integrate external labor market signals.

CONCLUSION

Internal labor supply forecasting is essential not only for reducing human resource costs and improving planning efficiency but also for enhancing organizational productivity and sustaining human capital. This study has demonstrated the applicability and value of Markov chain analysis for workforce planning at Baganuur JSC, Mongolia's principal state-owned coal mining company.

The analysis reveals a pronounced and accelerating aging trend in the workforce. Under baseline projections, approximately 40% of employees will be aged 50 or above by 2035, with this share rising further in subsequent decades. This structural shift poses material risks to operational continuity and the retention of specialized expertise. Scenario analysis demonstrates that proactive, youth-focused recruitment policies and accelerated succession planning can measurably moderate these risks.

Beyond Baganuur JSC, the findings highlight a broader need for systematic, quantitative HR planning in Mongolia's mining sector. Most enterprises lack the analytical infrastructure to anticipate workforce transitions, rendering them reactive rather than strategic in their HR management. The Markov chain framework applied here offers a transferable, low-cost methodology that can be adopted by other companies in the sector to improve workforce sustainability.

Future research should extend this framework by incorporating external labor market dynamics, applying non-stationary transition models, and conducting longitudinal validation of the forecasts presented in this study.

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10. The transition dynamics visualized in the matrix heatmap (see Figure 1) confirm the high stability of the core workforce, while highlighting the deterministic nature of age-based transitions.

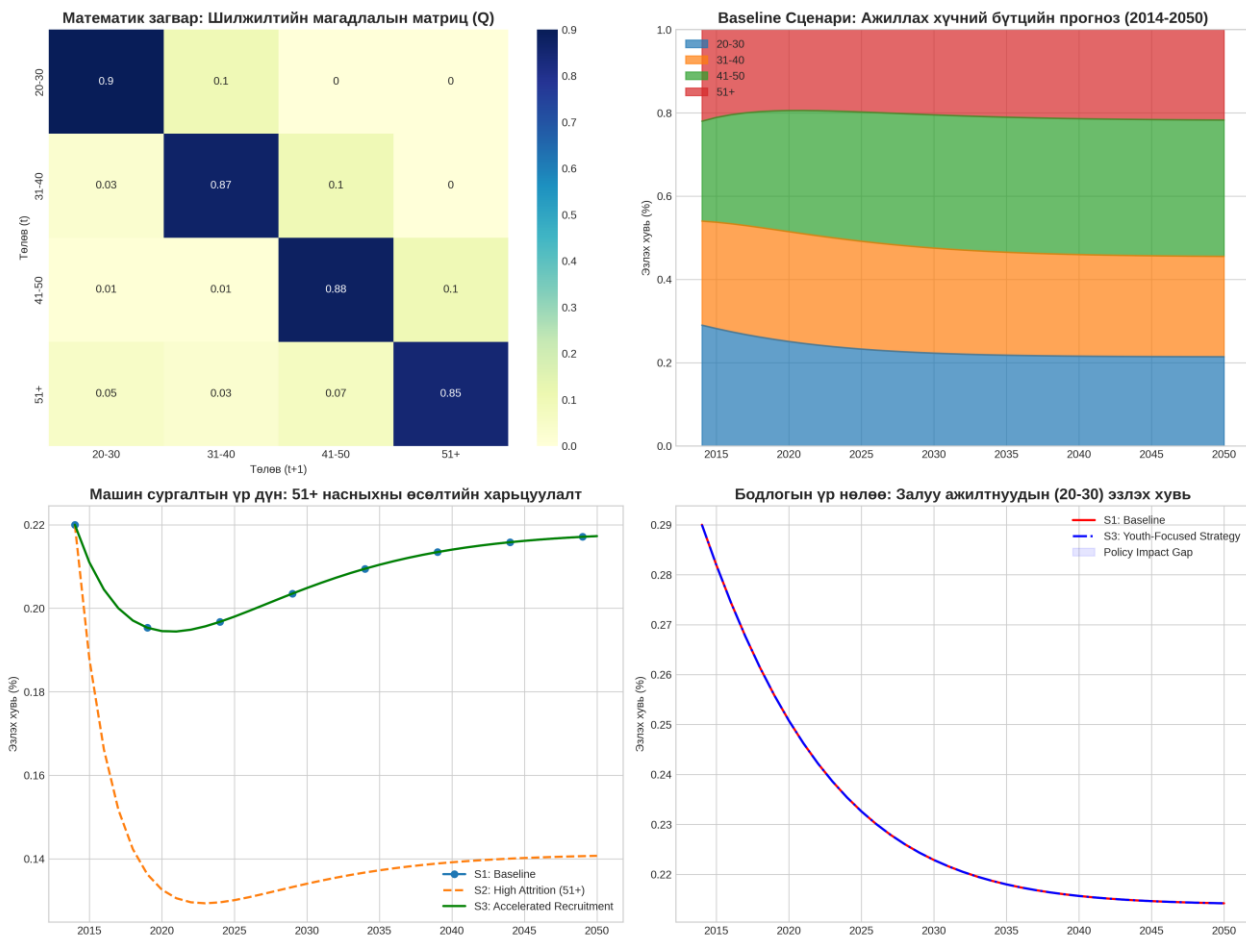


Figure 1. Integrated Analysis of Labor Supply Projections and Scenario Modeling: (A) Transition Heatmap, (B) Baseline Trend, (C) Aging Risk Comparison, (D) Youth Renewal Impact.

Global industry leaders such as Rio Tinto and BHP have successfully addressed aging workforce challenges through autonomous operations and phased retirement programs. These strategies allow experienced personnel to transition into advisory or remote-operation roles, mitigating physical health risks while retaining institutional knowledge. In the Mongolian context, Oyu Tolgoi LLC’s Graduate Development Programme and Erdenet Mining Corporation’s systematic knowledge management initiatives provide proven localized benchmarks for workforce renewal and human capital sustainability (Erdenet Mining Corp, 2025; Oyu Tolgoi, 2026).