Estimation of Production and Revenue Development in Granite Artisanal and Small Scale Mining Using Markovian Model

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Abstract
In this study, an algorithm is proposed for estimating revenue development for artisanal and small scale granite mining based on information of respective gender coefficients of involvement, respective gender granite cracking rates per day, Markovian dynamic programming concept, and standardization cost and criteria. This is particularly important because of a need to evaluate artisanal and small scale mining for standardization and control of practice in terms of gender involvement, environmental health, safety, and job creation. The results show that estimated cost of standardization for granite artisanal and small scale mining in Southwest Nigeria is approximately 10 million naira and that revenue development, exhibiting the Markovian property and criteria, can be expressed as a probabilistic dynamic programming model for forecasting revenue development and expected period it will take an artisanal and small scale mine to reach a cumulative revenue that can cover required costs for standardization of operations.

Keywords: artisanal and small scale mining, granite, revenue development, Markovian criteria, probabilistic dynamic programming, standardization cost, Southwest Nigeria.

INTRODUCTION
The contribution of artisanal and small scale mining (ASM) to mineral production is significant (International Labour Organization, 1999): in recent years ASM accounted for approximately 15 to 20% of the world’s nonfuel mineral production. According to studies by D’Souza (2004) ASM is a worldwide activity of major significance with tremendous potential for both positive and negative impacts at the community, national, regional, and global levels. ASM produces substantial percentages of the world’s supply of valuable minerals, generates export earnings and revenue for national governments, and provides employment for millions of people around the world. Up to 31 percent of industrial minerals, 20 percent of coal, 12 percent of metallic minerals, 10 percent of diamonds, and 75 percent of non-diamond gemstones come from ASM.

The returns for engaging in ASM for men and women miners, besides the general meager wages in cash, are very low. The costs in terms of social amenities, labour insecurity, and inaccessibility to finance, health hazards and gender marginalization are often not taken into consideration during artisanal mineral mining (Hentschel, Hrushka, & Priester, 2002; Women Rainforest Movement, 2004). Therefore, any study on production and revenue development aimed at improving ASM condition is relevant.

The field study location is within the Southwest basement complex of Nigeria, where granite and its mining and application are abundant. It is expected that the results obtained in the case study location can be extended to other parts of the basement complex for the same mineral. As is the case with other developing countries of Africa and other continents, Artisanal mining in Nigeria is a direct consequence of widespread poverty, caused by the decline of mining industry in Nigeria since the 1970’s and the introduction of Structural Adjustment Programme (SAP) in Nigeria in the 1980s. Today ASM dominates the current Nigeria mining sector, and over 90% of mining activities are illegal and substandard (Ministry of Solid Minerals Development, MSMD, 2002).

Nigeria is very rich in economic minerals mineable through ASM. The population is about 150 million and unemployment is a prevailing problem. Taking analogy of ASM operations in other developed countries of the world and in Africa, it is expedient and necessary to analyze ASM mining conditions and development in Nigeria with a view to developing recommendations for improved and increased participation of the unemployed (men and women alike) for economic development and standardization of operation.

Reliable estimates of employment levels in ASM indicate that the sector provides direct employment for between 13 million and 20 million people in at least 55 countries worldwide, and that an estimated 100 million people depend on ASM directly or indirectly for their livelihoods. While individual
ASM activities in any particular country may involve only a relatively small percentage of the population, collectively these numbers are of great significance, far outstripping the numbers attributed to the more capital-intensive, large-scale operations that typically come to mind in the context of mineral and gemstone mining. ASM offers a livelihood choice for many people in fragile, rural economies (where other employment options are limited) because the barriers to entry are low, requiring relatively limited financial, educational, and technological investment. Where ASM functions well, mining can yield much-needed capital to develop and support other positive economic and social activities, including farming, trading, education, and health care. Although the sector varies from country to country, it has significant (often untapped) potential to contribute on the national level to employment, income generation, gross domestic product, export earnings, and tax revenues. On the individual level, ASM offers possibilities to improve the productivity and well-being of people who live at the margins of society with limited alternative opportunities due to age, gender, or ethnic biases. In a number of countries, women comprise a substantial percentage of artisanal and small-scale workers. In Africa, for example, an average 60 percent of ASM workers are women (D’Souza, 2004).

**METHODOLOGY**

**Primary Data for Model Development**

Annual production and Revenue in ASM are uncertain (random in nature and a stochastic process). Underlying factors of this condition include the casual status of miners, manpower migration, and availability of investment funds. Primary data for this modeling are respective gender coefficients of involvement (Km - male and Kw - female), respective gender granite cracking rates per day (Pm - male, and Pw – female). Variables Km and Kw reflect possible scenarios of gender involvement for the three proposed ASM states (1-“fair”, 2-“poor”, and 3-“worse”). Pm and Pw represent production capacity parameters of granite ASM, used for evaluating output per year. The primary data were measured from the field in the Southwest rock basement complex of Nigeria as shown in Figure 1.

![Image](Figure 1)

Figure 1: Enlarged Map of South West Part of Nigeria Showing Rock Terrains and Selected Granite ASM Sites (Source: Authors’ Illustration).

**Modeling For Assessing Revenue Development And Gender Contribution For ASM**

Information in literature (Hentschel, Hrushka, & Priester, 2002) and on-site observations show that mining condition is composed of: mining operation condition (MO); personnel condition (PC); environmental, safety and health conditions (EHS); and others (public support and finance). Production, a consequence of the interaction of factors of mining condition, is chosen as indicator of mine’s potential (strength) to mitigating costs or improving mine condition. Production can be translated as revenue as shown in Figure 2.

![Image]
Estimation of Required Cost of Standardizing ASM Mining Condition

A standard ASM is one in which environmental, health, and safety standards are met. The production cost equations applied in this study for standard ASM conditions is expressed as in Equations (1) to (4). The most prominent cost component in ASM with respect to standardization is $RE_{std}$, Justifying Equation (4), and hence applied for evaluating standard granite ASM cost.

\[ C_{\text{std}} = D_{\text{FC}} + RE_{\text{std}} \]  
\[ D_{\text{FC}} = 10\% C_{\text{FC1}} + 20\% C_{\text{FC2}} \]

where $D_{\text{FC}}$ and $RE_{\text{std}}$ are annual depreciation on Fixed Capital FC and annual recurrent expenses respectively.

where $C_{\text{FC1}}$ is costs of tools, and $C_{\text{FC2}}$ is costs of transports, land and development, office equipment,

\[ RE_{\text{std}} = C_{\text{raw mat, etc}} + C_{\text{wage}} + C_{\text{EH&S}} \]

where $C_{\text{raw mat, etc}}$ is cost of raw materials, fuel etc, $C_{\text{wage}}$ is cost of standard wage, $C_{\text{EH&S}}$ is cost of standard environmental, health, and safety condition.

\[ C_{\text{std}} \approx RE_{\text{std}} \]

An expected Minimum standard required for mitigation of wage, environmental, health, and safety problems in granite ASM, based on field observation, is presented in Table 1. Cost data of protective equipment, based on market prices, are presented in Table 2.

<table>
<thead>
<tr>
<th>Problems areas</th>
<th>Risk</th>
<th>Solution: expected Minimum standard required for mitigation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wages</td>
<td>Subsistence @ N600/tone (N7200/nth @ 0.5 t/day)</td>
<td>N1000 naira/thone: N5000/th; 15000/nth @ 0.5 t/day</td>
<td>Government regulation is required to make managers increase the wage per ton. The balance can be sourced by N400 increase in price/tone</td>
</tr>
<tr>
<td>Environment, Health and Safety</td>
<td>Rock falls</td>
<td>helmets</td>
<td>Loan assistance is needed at start. Government can assist.</td>
</tr>
<tr>
<td></td>
<td>Flying debris</td>
<td>goggle;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tools</td>
<td>gloves;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flying debris</td>
<td>protective clothing;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Noise and vibration</td>
<td>ear stops;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Terrain and other accidents</td>
<td>boots;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dust</td>
<td>Face masks (air filter)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crime</td>
<td>security</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Wages, Environmental, Health and Safety Risks in Granite ASM
Table 2: Cost Data for Standard Safety and Health Equipment

<table>
<thead>
<tr>
<th>Items</th>
<th>Qty per cap.per yr</th>
<th>Unit cost</th>
<th>Total/yr</th>
<th>Total/2yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helmets</td>
<td>1</td>
<td>5000</td>
<td>5000</td>
<td>10000</td>
</tr>
<tr>
<td>goggles:</td>
<td>1</td>
<td>5000</td>
<td>5000</td>
<td>10000</td>
</tr>
<tr>
<td>gloves:</td>
<td>1</td>
<td>5000</td>
<td>5000</td>
<td>10000</td>
</tr>
<tr>
<td>protective clothing:</td>
<td>1</td>
<td>20000</td>
<td>20000</td>
<td>40000</td>
</tr>
<tr>
<td>ear stops:</td>
<td>1</td>
<td>10000</td>
<td>10000</td>
<td>20000</td>
</tr>
<tr>
<td>mountain boots</td>
<td>1</td>
<td>20000</td>
<td>20000</td>
<td>40000</td>
</tr>
<tr>
<td>Face masks</td>
<td>12</td>
<td>200</td>
<td>2400</td>
<td>4800</td>
</tr>
<tr>
<td>sum total</td>
<td></td>
<td></td>
<td>58400</td>
<td>116800</td>
</tr>
<tr>
<td>Security</td>
<td>12</td>
<td>15000</td>
<td>180000</td>
<td>360000</td>
</tr>
<tr>
<td>First aid kits</td>
<td></td>
<td>100,000</td>
<td>100,000</td>
<td></td>
</tr>
</tbody>
</table>

Model Construction for ASM Revenue Development and Gender Involvement, Based on Markov’s Criteria

ASM revenue development is considered as a finite-state probabilistic Dynamic Programming (DP) problem based on the following: ASM condition and development at a given period is not deterministic (probabilistic in nature) and ASM exhibits Markovian criteria (Taha, 2008; Sharma, 2009; Hillier & Lieberman, 1980); long term development can be decomposed into stages (years); variability of gender involvement scenarios is high; dynamics of ASM state can be considered as exhibiting Markovian property, i.e., ASM condition in the next time-stage depends on current condition of a mineral and not on historic conditions; and classification of ASM state into three categories is feasible: fair, poor, and worse. The number of transition states is finite and estimation of a set of initial stationary probabilities for them is feasible. Optimal cumulative revenue $f_d(i)$ for ASM, in state $i$ and year stage $\eta$ for $k$ scenarios of gender involvement, was formulated as forward recursive probabilistic DP equation based on Markov’s criteria and expected monetary value criterion, which relates $f_d(i)$ with $f_{d+1}(i)$ as in:

$$
\begin{align*}
    f_\eta (i) &= \max \sum_{j=1}^{m} p_{ij} \left[ f_\eta (j) + f_{\eta+1} (j) \right] \\
    \eta &= 1, 2, 3, \ldots, H
\end{align*}
$$

where $f_{\eta+1} (j) = 0$ for all $j$

where $r_{ij}$ is revenue matrix and $p_{ij}$ is transition probability.

Let $V_i$ represent $\sum_{j=1}^{m} p_{ij} r_{ij}$, which is the expected revenue from a single stage transition to state $i$ given alternative $k$ then

$$
\begin{align*}
    f_\eta (i) &= \max_{\phi} \left[ V_i + \sum_{j=1}^{m} p_{ij} f_{\eta+1} (j) \right] \\
    \eta &= 1, 2, 3, \ldots, H
\end{align*}
$$

Let $\phi$ represent cost of mitigating ASM problem for $k$ involvement. Then balance revenue for standardization in stage $\eta$ is expressed as:

$$
\Delta f_\eta (i) = \phi - f_\eta (i),
$$

If $\Delta f_\eta (i) \geq 0$, then cumulative revenue is yet to cover cost of standardization, and if $\Delta f_\eta (i) \leq 0$ – cumulative revenue can cover cost of standardization. Introducing discount factor $\alpha$, Equation (5) becomes modified as expressed in Equation (8)

$$
\begin{align*}
    f_\eta (i) &= \max_{\phi} \left[ V_i + \alpha \sum_{j=1}^{m} p_{ij} f_{\eta+1} (j) \right] \\
    f_{\eta-1} (i) &= \max_{\phi} \left[ V_i \right]
\end{align*}
$$

Expanding (8) the model is decomposed into a system of per-stage solutions:

$$
\begin{align*}
    f_1 (i) &= \max_{\phi} \left[ V_{i1} + \alpha \sum_{j=1}^{m} p_{ij} f_{2} (j), V_{i2} + \alpha \sum_{j=1}^{m} p_{ij} f_{3} (j), \ldots, V_{iK} + \alpha \sum_{j=1}^{m} p_{ij} f_{H} (j) \right] \\
    f_2 (i) &= \max_{\phi} \left[ V_{i1} + \alpha \sum_{j=1}^{m} p_{ij} f_{2} (j), V_{i2} + \alpha \sum_{j=1}^{m} p_{ij} f_{3} (j), \ldots, V_{iK} + \alpha \sum_{j=1}^{m} p_{ij} f_{H} (j) \right] \\
    f_3 (i) &= \max_{\phi} \left[ V_{i1} + \alpha \sum_{j=1}^{m} p_{ij} f_{2} (j), V_{i2} + \alpha \sum_{j=1}^{m} p_{ij} f_{3} (j), \ldots, V_{iK} + \alpha \sum_{j=1}^{m} p_{ij} f_{H} (j) \right] \\
\vdots
    f_{K} (i) &= \max_{\phi} \left[ V_{i1} + \alpha \sum_{j=1}^{m} p_{ij} f_{2} (j), V_{i2} + \alpha \sum_{j=1}^{m} p_{ij} f_{3} (j), \ldots, V_{iK} + \alpha \sum_{j=1}^{m} p_{ij} f_{H} (j) \right]
\end{align*}
$$

$\Delta f_\eta (i) = \phi - f_\eta (i)$

if $\Delta f_\eta (i) \leq 0$ end, else proceed to next stage
Rewriting Equation 11 in symbol of revenue $R$:

$$ R_\eta (i) = \max_k \left[ V^k + \sum_{j=1}^m p_{\eta}^j R_{\eta - 1}^*(j) \right], \quad (11) $$

where $i = 1, 2, 3$ (ASM conditions),

$R_{\eta - 1}^*(j)$ is optimal cumulative revenue in stage $\eta - 1$.

Balance cost of standardization $\Delta R_\eta (i)$ at $\eta$-th period of ASM production in state $i$:

$$ \Delta R_\eta (i) = R^{std} - R_\eta (i), \quad (12) $$

where $R^{std}$ is standard cost of standardization.

Transition revenue matrix is evaluated as in Equation (13)

$$ r_{ij}^k = \text{mean} \left[ r_{mn+1}^k(i), r_{n+1}^k(j) \right], \quad (13) $$

where $r_{mn}^k(i)$ is revenue of ASM in stage $n+1$ and state $i$; and $r_{n+1}^k(j)$ is revenue of ASM in stage $n$ and state $j$.

Transition probabilities were determined using Supposition Method (Sharma, 2009). Supposition method is used, which captures possible transition probability suppositions.

Table 3 presents expected annual costs, revenues, and profits of standard and standard granite ASM respectively as function of manpower per day. An analysis of the table shows that, for fair manpower, the minimum cost range of standard ASM per year is between 7.33 and 9.23 million naira or under 10 million naira. For substandard ASM, it is between 5.8 and 7.4 million naira. This implies that an investment of over 7.3 million is necessary for upgrading ASM in order to operate at admissible standards that can mitigate existing problems of wage, health, and safety, and environmental conditions.
CONCLUSIONS AND RECOMMENDATIONS

From an analysis of the results, minimum cost of standard granite ASM (R\textsuperscript{std}) per yr for an average fair production is approximately N7.4 million without consideration for standardization, and N9.23 million with consideration for standardization of operations. This implies that an investment of about N9.23 million or a rounded up figure of N10 million is necessary for upgrading ASM in order to operate at admissible standards that can mitigate existing problems of wage, health and safety, and environmental conditions. Revenue in ASM is proposed as exhibiting Markovian property and criteria, and therefore its development can be expressed mathematically using a Markovian probabilistic dynamic programming model, as developed.

The ASM operations can be expressed as a DP model, based on the stochastic nature of production and Markovian property and criteria that this kind of mining was observed to exhibit, for determination of probabilistic cumulative production or revenue over any given period for a given mineral. This is particularly useful for forecasting the ability or feasibility of a given ASM to mitigate problems of personnel, environmental, health and safety (EHS), common to all ASM activities, in terms of revenue; and evaluating gender contribution. Also, the model could be used to estimate the viability of approving credit facilities to given cases of ASM by financial institutions (banks, state, etc).

REFERENCES


