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Trade-off Assessment on Two Steel Ball Brands Use at the Ball Mill Plant of a Ghanaian Mine

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Abstract

Realistically, this research shows that, the type or brand of input reagent such as steel ball is a vital parameter to be considered to ensure cost saving in mineral processing business. Logically, the study pointed out the shortfall in the acceptance of input reagent (steel ball) of a production system on only the unit price variance for different items. Clearly, the paper aims at closing the lack of information gap existing in the Ghanaian mining company to overcome the situation of compromising efficiency of the plant production whilst maximizing profit. Furthermore, assessing the overall effect by taking into consideration the operating variables, painted a pragmatic and reliable picture of the prevailing scenario. Consequently, company 1 with a mean discharge product of 49.42 % passing 150 μm was at a cost of US$1.68 whiles company 2 with mean discharge product of 50.12 % passing 150 μm was at a cost of US$1.30. Comparatively, company 2 brand of steel ball usage gave an overall trade-off of 0.8 % as against the usage of company 1 steel ball brand. The paper recommended the use of company 2 steel ball brand as a cost saving enhancement decision for gold production in the Ghanaian Mine.

Keywords: percentage passing, milling, retain, micron, steel ball brand

1. Introduction

Trade-off is the gain in accepting less or sacrifice one commodity or item for the other. Cautious and logical evaluation of trade-off involves comparing cost and benefit of available alternatives with each other. Economically, trade-off expresses the opportunity cost in most favorite potential alternative (Johnson, 2005; Hill, 2015). This includes, undertaking cost saving assessment that focus on optimizing cost in an endeavour. Cost saving initiative is the decision or action that will result in the fulfillment of a lower cost objective than the historical cost or the projected cost of an item (Hornby, 2010). Invariably, to enhance cost saving initiative, element-by-element examination of the estimated or actual cost of contract performance or item being used cannot be overemphasized. The goal is to form an opinion on whether the proposed costs are in line with pragmatic and efficient performance cost (Weisbrod and Hansen, 1981). At the Carbon in leach (C.I.L) Plant of the Ghanaian mine in this research, there are several cost centers with cost elements of distinctive total cost dependency. Steel ball consumption implies the amount of steel ball used in a particular time period to enhance grinding of ore in tumbling Mill (a designed drum which use rotational motion to generate abrasive and impact forces between steel balls and ore to effect ore grinding). At the end of grinding process, the steels are completely destroyed whiles the ore break down into relatively finer particle size fractions as compared to the ore size (feed ore size) before the start of grinding process. Obviously, the amount of steel ball use in achieving a given size particle is a function of the level at which a give steel ball type can withstand the destruction effect of a particular ore. This trade-off assessment on steel ball consumption seeks to establish the cost effectiveness of the steel ball brand for the milling operation at the C.I.L Plant. Additionally, the high cost of steel balls has a direct effect on the increasing cost of production at the C.I.L plant process. This paper is to close the lack of information (i.e. information on cost effective steel ball brand) gap existing in the Ghana mine. This will help the company to overcome the situation of compromising efficiency of the plant by trying to maximize profit under pretext of cheap price. The framework of this research covers, quantitative evaluation of the use of two different brands of steel balls in sequential order as input reagent at plant condition for 30 days period. The paper aims at selecting a cost effective steel ball brand for the mineral process plant of the Ghanaian mine in this research. Applicably, Bertsimas, Farias and Trichakis (2012), assesses the problem of designing the right objective which resolves the normal difficulty of selecting between efficiency and fairness in the perspective of a framework that covers a number of resource allocation under the topic On the Efficiency-Fairness Trade-off.

1.1 Cost Factors and Analysis at Steel Ball Consumption at the Ghanaian Mine Processing Plant

The processing plant of the Ghanaian mine being under studied, operates at a throughput capacity of 1,532 ton of ore per hour with an expected daily production of 36,000 tones at 23.5 hours plant availability. The input elements (reagents) for ore grinding process at the Ball Mill plant are electric power and two brands (60mm steel ball of company 1 and 2). The cost of Ball Mill power usage is given as US$ 0.17 for kilowatt hour per ton of ore milled whiles the company 1 and 2 steel ball brands cost US$1237 and US$1338 per ton of steel balls respectively (Technical Report, 2016). Critically, it will be suicidal to select any alternative of reagent without given thorough assessment to it effect on the total production cost of plant operation. Therefore, the seemingly lower unit cost and a supplier's quality indication of one reagent as compared to another, will not necessarily justify its selection for usage. Imperatively, cost allocation, cost-effectiveness analysis, and cost-benefit analysis are ranges of cost analysis methods for evaluating steel ball consumption efficiency at the processing plant operation. They range from fairly simple program-level methods to highly technical and specialized methods. Cost allocation is a simpler concept than either cost-benefit analysis or cost-effectiveness analysis. At the processing plant operation, it means setting up budgeting and accounting systems in a way that allows managers to determine a unit cost of service gain out of a given type of steel ball. This information is mostly a management tool that focuses on decision making. However, since the units measured are also outcomes of interest to evaluators, cost allocation provides some of the basic information needed to conduct more determined cost analyses (Kettner, Moroney & Martin, 1990; Zeckhauser, 1975). In furtherance of authenticating this assessment, power consumption and end product particle size of the different brands of steel ball used were evaluated to point out the tradeoff that may be obtained in using a particular type of steel ball. This gives a holistic assessment that has the potential of given a reliable selection of the brand of steel ball require for efficient plant operation. Hence, at the processing plant operation, the amount of steel balls use to transform a given quantity of ore to a finer grind size fraction, measures the steel ball consumption rate. The consumption rate is then achieved by relating a given mass quantity of steel balls use to grind a unit mass quantity of ore. The unit expression of steel ball consumption rate is given as gram per ton of ore (g/t) or kilogram per ton of ore (Kg/t). Furthermore, power usage in terms of kilowatt hour per ton of ore grinded and percentage particle size passing through a 150 micron (μm) aperture screen target, are the parameters for evaluating performance of a given steel ball brand used in grinding process.

2. Material and Method Used

Fundamentally, the insufficiency of information on the trade-off of steel ball usage at the process plant is a recipe for production deficiencies. Therefore, monthly production report records of the two different brands (i.e. company 1 and 2) of steel balls, used under constant plant operating conditions were studied to ascertain their respective opportunity cost with regards to end product as a target. According to Young (2013), comparison matrix is a useful tool for establishing criteria priorities of the given opportunities. Basically, from Young's point of view, these criteria priorities are formed out of weighted scores generated from recorded values of the items under consideration. This paper points to undertaking holistic evaluation of all the related parameters to arrive at practical trade-off for the two steel ball brands. The steel balls under consideration in this research, have equal parameters that relate to the wear rate. Hence cost analysis technic of unit cost evaluation was used to ascertain indices of the two steel ball brands for the process plant. Additionally, the power draw trends from a Scada system (i.e. automatic control and recording system) were used to evaluate the power consumption levels of the different steel ball brands. Saunder, lewis and Thornhill, (2009), affirmed the examination of simple index numbers as suitable method for comparing relative changes of different unit variables for drawing pragmatic conclusion. Hence, from the production reports, different brands of steel balls and their corresponding discharge product variables, call for the use of quantitative analysis of simple index numbers as the appropriate model for trade-off evaluations. Therefore, quantitative evaluations of power usage, steel ball consumption rate and corresponding effects of the different steel ball brands on the particle size fractions produced were obtained to enhance realistic conclusions.

3. Result from Daily Operational Report Data

Operational reports for 30 days usage of 60 mm steel balls of each brand (Steel Ball Company 1 and 2) in the Ball Mill at controllable amount at mill power set point of not less than 11000 KWh were studied. The monthly production report parameters use for this assessment includes the daily records of steel ball consumption, mill power usage and tonnage milled with corresponding throughput records. Additionally, Laboratory tested particle size fractions for percentage retained on 150 µm aperture screen (+150 µm particle size fraction) for Ball Mill feed and discharge were monitored throughout the 30 days period (Technical Report, 2016). These parameters were subjected to appropriate quantitative analysis to generate the needed indications towards the trade-off focus. The tables 1and 2 were the results obtained from the daily report of the said periods for the two brands of steel balls. The tables show appropriately the summation of daily steel ball consumption and milled tonnage per day with average values for power draw, throughput, Ball Mill feed and discharge in line with pragmatic decision considerations.

Table 1. Company 1 Steel ball daily plant operating report

No. Day	Daily Steel Ball Consumption (Kg)	Power Draw, KWh	Daily milled tonnes, t	Throughput, t/h	Ball Mill Feed +150µm, %	Average Ball Mill Discharge +150µm, %
1	30,000	11,983	24,929	1275	75.52	62.27
2	50,000	11,841	36,102	1504	74.49	58.64
3	40,000	11,909	37,192	1550	81.05	68.85
4	40,000	11,965	35,321	1472	77.46	61.57
5	55,000	11,966	33,944	1414	79.55	54.43
6	35,000	11,932	32,772	1366	81.63	59.87
7	40,000	11,899	35,299	1471	84.23	61.76
8	40,000	12,023	33,901	1414	80.71	50.78
9	40,000	11,975	36,255	1511	82.42	60.49
10	30,000	11,962	34,735	1447	78.95	58.71
11	30,000	11,895	34,727	1447	69.88	55.59
12	30,000	11,828	34,719	1521	78.07	59.44
13	15,000	11,748	14,175	1284	77.93	65.31
14	6,000	11,544	32,374	1494	78.95	62.26
15	50,000	11,377	32,937	1386	80.34	50.58
16	40,000	11,395	37,266	1553	77.32	56.13
17	60,000	11,626	35,575	1592	80.34	55.11
18	47,000	11,873	36,708	1530	82.92	61.32
19	43,000	11,980	37,218	1559	81.79	61.67
20	35,000	11,975	36,364	1515	81.47	57.21
21	28,000	11,925	33,459	1404	81.18	67.26
22	33,000	11,739	38,595	1608	80.36	65.06
23	34,000	11,783	36,020	1580	77.63	68.58
24	36,000	11,725	30,509	1278	78.21	53.03
25	28,000	11,959	36,617	1526	79.11	55.80
26	26,000	11,772	35,686	1564	63.03	59.53
27	52,000	11,929	31,653	1319	81.16	60.55
28	25,000	11,775	29,693	1242	78.48	57.80
29	45,000	11,675	31,759	1362	82.19	56.10
30	30,000	11,875	28,415	1193	83.83	53.03
AVERAGE/SUM	**1093000**	**11828**	**1004920**	**1446**	**79.23**	**59.29**

Table 2. Company 2 Steel Ball Daily Operation Report

No. Day	**Daily Steel Ball Consumption (Kg)**	**Power Draw, KWh**	**Daily milled tonnes, t**	**Throughput, t/h**	**Ball Mill Feed +150 μm, %**	**Average Ball Mill Discharge +150 μm, %**
1	20,000	11,498	34,248	1427	81.51	70.67
2	20,000	11,469	34,211	1425	81.21	66.38
3	20,000	11,406	35,667	1486	78.01	64.46
4	15,000	11,464	28,823	1241	81.96	65.11
5	20,000	11,462	31,400	1403	76.64	64.39
6	0	11,643	2,225	968	75.08	63.39
7	0	11,448	13,504	1286	79.59	51.35
8	18,000	11,353	30,300	1335	79.13	74.67
9	18,000	11,346	36,837	1535	82.07	60.26
10	16,000	11,504	33,594	1402	69.07	60.17
11	36,000	11,348	34,556	1440	64.18	51.66
12	15,000	11,264	30,186	1362	60.08	49.88
13	40,000	11,238	35,567	1482	71.66	63.63
14	36,000	11,430	33,311	1464	81.69	71.19
15	0	11,649	15,583	729	78.63	65.93
16	20,000	11,396	27,232	1295	68.44	56.75
17	30,000	11,358	34,518	1443	79.71	65.69
18	30,000	11,503	31,031	1320	79.37	68.64
19	36,000	11,507	30,526	1296	77.83	64.01
20	60,000	11,535	34,140	1423	77.71	64.91
21	40,000	11,929	36,279	1512	79.04	75.90
22	45,000	11,998	33,695	1446	77.92	58.08
23	45,000	11,949	34,198	1439	74.56	54.90
24	34,000	12,005	27,720	1171	74.71	62.76
25	36,000	11,973	35,291	1470	74.88	61.21
26	55,000	11,969	33,345	1389	73.08	61.42
27	40,000	11,966	33,964	1415	74.92	64.35
28	0	12,009	31,798	1325	73.78	70.19
29	0	11,892	34,580	1492	77.04	72.10
30	0	11,970	32,497	1449	78.12	61.23
AVERAGE/SUM	**745000**	**11616**	**920829**	**1362**	**76.28**	**61.23**

4. Discussion and Analysis of Results

Tables 3 provides mill discharge size fractions, indicated as -150 μm discharge percentage (i.e. percentage of size fraction passing through 150 μm sizing screen) for company 1 and 2 brand steel balls. Respective dried weight of particle size fraction retained on 150 μm was measured by the use of digital weighing scale after performing sizing test on a given total sample weight. The percentage passing through 150 μm was deduced by subtracting the weight retained on the150 μm screen from the given total sample weight for the test. The resultant weight (i.e. the weight of sample passing through 150 μm screen) is expressed as percentage of the total sample weight. This gave the corresponding percentage passing through the150 μm screen of the various sample days. Statistically, the standard deviations for company 1 steel ball parameters are 4.82, 0.07 and 0.09 corresponding to -150 μm discharge percentage, steel ball consumption rate and power draw respectively. Similarly, company 2 steel ball brand has 6.48, 0.13 and 0.89 as standard deviation for -150 μm discharge percentage, steel ball consumption rate and power draw respectively. These relatively low standard deviations for the respective variables justify the use of the resultant average values (mean figures) as representative figures for the trade-off assessment.

Table 3. Company 1and 2 Steel Ball effect on Ball Mill Discharge Size fractions

Company 1 Steel Ball				Company 2 Steel Ball		
No. Day	**-150 um Discharge, %**	**Steel ball consumption, Kg/t**	**Power/ton, Kwh/t**	**- 150 um Discharge, %**	**Steel ball consumption, Kg/t**	**Power/ton, Kwh/t**
1	37.74	1.20	0.481	29.33	0.58	0.336
2	41.36	1.31	0.328	33.62	0.58	0.335
3	31.15	1.22	0.320	35.54	0.58	0.320
4	38.43	1.20	0.339	34.89	0.56	0.398
5	45.57	1.28	0.353	35.61	0.58	0.365
6	40.13	1.25	0.364	36.61	0.57	5.233
7	38.24	1.23	0.337	48.65	0.53	0.848
8	49.22	1.22	0.355	25.33	0.54	0.375
9	39.51	1.21	0.330	39.74	0.53	0.308
10	41.29	1.17	0.344	39.83	0.52	0.342
11	44.41	1.15	0.343	48.34	0.58	0.328
12	40.56	1.12	0.341	50.12	0.57	0.373
13	34.69	1.12	0.829	36.37	0.62	0.316
14	37.74	1.05	0.357	28.81	0.66	0.343
15	49.42	1.09	0.345	34.07	0.64	0.748
16	43.87	1.08	0.306	43.25	0.64	0.418
17	44.89	1.12	0.327	34.31	0.66	0.329
18	38.68	1.13	0.323	31.36	0.68	0.371
19	38.33	1.13	0.322	35.99	0.70	0.377
20	42.79	1.12	0.329	35.09	0.77	0.338
21	32.74	1.11	0.356	24.1	0.79	0.329
22	34.94	1.10	0.304	41.92	0.81	0.356
23	31.42	1.09	0.327	45.1	0.84	0.349
24	46.97	1.09	0.384	37.24	0.85	0.433
25	44.20	1.08	0.327	38.79	0.86	0.339
26	40.47	1.07	0.330	38.58	0.89	0.359
27	39.45	1.09	0.377	35.65	0.91	0.352
28	42.20	1.08	0.397	29.81	0.87	0.378
29	43.90	1.09	0.368	27.9	0.84	0.344
30	46.97	1.09	0.418	38.77	0.81	0.368
Unit Value	**49.42**	**1.31**	**0.353**	**50.12**	**0.91**	**0.378**
Standard Deviation	**4.82**	**0.07**	**0.09**	**6.48**	**0.13**	**0.89**

Tables 4 portrays the input and output cost evaluation indices for the two steel brands. Additionally, the respective power draw and calculated unit consumption per tonnage of ore milled are shown with their associated cost values. Company 1 steel ball brand has consumption of 1.31kg/t and power usage of 0.353Kwh/t with cost of US$1.62 and US$0.06 respectively. These gave a resultant production cost of US$1.68 for producing 49.42% particle size fraction passing through 150 µm screen. Similarly, Company 2 steel ball brand has consumption of 0.91kg/t and power usage of 0.378Kwh/t with cost of US$1.23 and US$0.07 respectively giving a total production cost of US$1.30 for producing 50.12% particle size fraction passing through 150 µm screen. The total input cost per percentage passing 150 µm for company 1 and 2 steel balls are US$0.034/% and US$0.026/% respectively. Hence, percentage variance of 0.8% between total input cost per percentage passing 150 µm (-150 µm discharge) indicates the trade-off resulting from preferring one product (i.e. Company 1 or 2 steel balls) against the other. The relatively lower input cost per total input cost per percentage passing 150 µm for company 2 as compared to that of company 1 steel balls point to a cost saving of 0.8% in favour of using company 2 steel balls. Conversely, using company 1 steel balls will generate a deficit of 0.8% as compared to company 2 steel balls.

Pragmatically, using company 1 steel ball brand for milling 36000 tons of ore per day at steel ball consumption rate of 1.31kg/t of ore implies a usage of 46.80 tons of steel balls per day. This translates into US$57891.60 at US$1237 per a ton of steel ball. Additionally, using 0.353Kwh/t of power for milling 36000 tons of ore per day will generate a total power usage of 12708Kwh at a cost of US$0.18 per Kwh. This implies total power cost of US$2287.44 per day. Hence, the overall cost of producing 49.42% particle size fraction passing 150 µm is US$60051.60 per day. Conversely, applying trade-off of 0.80% (percentage variance) gave total amount to cost saving of US$480.00 per day which will be equal to US$175349.65 per year upon using company 2 steel ball brand instead of company 1 steel balls for milling.

Table 4. Input and Output Cost evaluation indices for the two steel brands

Production Element	Cost element	Company 1 Forged Steel Ball		Company 2 Forged Steel Ball	
		Unit value	**Cost, US$**	**Unit value**	**Cost, US$**
Input	**Steel Ball consumption, Kg/t**	**1.31**	**1.62**	**0.91**	**1.23**
	Power per ton, Kwh/t	**0.353**	**0.060**	**0.378**	**0.07**
	Total Input Cost, US$	**1.68**		**1.30**	
output	**-150 µm discharge, %**	**49.42**	**1.68**	**50.12**	**1.30**
	Total Input cost per -150 µm discharge, US$/%	**0.034**		**0.026**	
tradeoff	**Total Input cost per -150 µm discharge Variance, US$/%**	**0.008**			
	Percentage Variance, %	**0.8**			

4.1 Evaluating the Trade-off at Variable Prices for Power and the Two Steel Ball Brands

Analytically, decision matrix is one of the numerous format that can be used to assess the tradeoff of given items by evaluating the difference in total scores of respective weighted criteria for variables under consideration (Brady, 2011; Morán-Ordóñez, et.al, 2016; Yoe, 2002). Three input variable items used in assessing the trade-off for the two brands of steel brands are power cost, steel ball and -150 µm discharge percentage. Table 5 shows various trade-off obtained under the assumption of changes in cost of power usage with Company 2 steel ball total input cost per -150 µm discharge value as the reference point. Assessing the trade-off at assumed changes in power cost per kilowatt hour (Kwh) of US$ 0, US$5, US$10, US$15, US$20, US$25 and US$30 generate trade-off (Percentage variance) values of 0.850%, 0.650%, 0.451%, 0.251%, 0.052%, -0.148% and -0.347% respectively. From Sharma (2011), figure 1 shows the linear trend with the trade-off in percentage variance as Y (dependent variable) and power cost per kilowatt hour as X (independent variable). This gave y = -0.0399x + 0.8496 as linear equation. Deduction from the given equation shows that, increasing power cost per kilowatt hour higher than US$21.29, the trade-off will be negative. This implies that, at power cost per kilowatt hour higher than US$21.29, it will be beneficial to buy or use company 1 brand of steel balls instead of buying company 2 steel balls. Similarly, all things other things being equal, from table 6, the trade-off deductions under the assumption of changes in unit cost per ton of Company 1 steel ball brand at US$500, US$700, US$900, US$1100, US$1300, US$1500 and US$1700 generate trade-off (Percentage variance) values of 0.011%, 0.006%, 0.001%, -0.005%, -0.010, -0.015% and -0.021% respectively. Figure 2 shows the linear trend with the trade-off in percentage variance as Y (dependent variable) and unit cost per ton of Company 1 steel ball brand as X (independent variable). This gave y = -0.0027x + 2.4365 as the linear equation. Deduction from the given equation shows that, at unit price above US$902.41per ton for company 1 steel ball brand, the trade-off will be negative. This implies that, at unit price above US$902,41per ton for company 1 steel ball brand, it will be beneficial or profitable to buy or use company 2 brand of steel balls instead of buying company 1 steel balls. Subjecting the changes in price of power and the two steel ball brands to linear regression analysis show graphs with $r^2 = 1$ which is a perfect reliable relation for forecasting or prediction.

However, from table 7 various trade-off obtained under the assumption of changes in unit cost per ton of Company 2 steel ball brand with the corresponding total input cost per -150 µm discharge value with cost per ton of Company 1 as the reference point. Assessing the trade-off at assumed changes in unit cost per ton of Company 2 steel ball brand of US$1300, US$1400, US$1500, US$1600, US$1700, US$1800 and US$1900 generating trade-off (Percentage variance) values of 0.91146%, 0.72989%, 0.54833%, 0.3667%, 0.18520%, 0.00364% and -0.17793% respectively. Figure 3 shows the linear trend with the equation y = -0.0018x + 3.2718 The Y (dependent variable) axis represents trade-off in percentage variance as and unit cost per ton of Company 2 steel ball brand is denoted as X (independent variable) axis (Sharma, 2011; Nau, 2014). Deduction from the given equation shows that, at unit price higher than US$1817.67 per ton for company 2 steel ball brand, the trade-off will be negative. This implies that, at unit price higher than US$1817.67per ton for company 2 steel ball brand, it will be beneficial or profitable to buy or use company 1 brand of steel balls at a price US$ 1237 per ton instead of buying company 2 steel balls.

Table 5. Trade-off at variable prices for power input

		Peroids	1	2	3	4	5	6	7
Input Element		**Change Power cost per Kwh, US$**	**0**	**5**	**10**	**15**	**20**	**25**	**30**
	Company 1 Forged Steel Ball	**Unit cost per ton of Steel Ball, US$**	**1237**	**1237**	**1237**	**1237**	**1237**	**1237**	**1237**
		Steel Ball consumption, Kg/t	**1.31**	**1.31**	**1.31**	**1.31**	**1.31**	**1.31**	**1.31**
		Steel Ball consumption cost, US$	**1.62047**	**1.62047**	**1.62047**	**1.62047**	**1.62047**	**1.62047**	**1.62047**
		Power usage per ton, Kwh/t	**0.353**	**0.353**	**0.353**	**0.353**	**0.353**	**0.353**	**0.353**
		Power cost per ton, US$	**0**	**1.765**	**3.53**	**5.295**	**7.06**	**8.825**	**10.59**
		Total Input Cost, US$	**1.62047**	**3.38547**	**5.15047**	**6.91547**	**8.68047**	**10.4455**	**12.2105**
Output Element		**-150 µm discharge, %**	**49.42**	**49.42**	**49.42**	**49.42**	**49.42**	**49.42**	**49.42**
		Total Input cost per -150 µm discharge, US$/%	**0.03279**	**0.0685**	**0.10422**	**0.13993**	**0.17565**	**0.21136**	**0.24708**
Input Element	**Company 2 Forged Steel Ball**	**Unit cost per ton of Steel Ball, US$**	**1338**	**1338**	**1338**	**1338**	**1338**	**1338**	**1338**
		Steel Ball consumption, Kg/t	**0.91**	**0.91**	**0.91**	**0.91**	**0.91**	**0.91**	**0.91**
		Steel Ball consumption cost, US$	**1.21758**	**1.21758**	**1.21758**	**1.21758**	**1.21758**	**1.21758**	**1.21758**
		Power usage per ton, Kwh/t	**0.378**	**0.378**	**0.378**	**0.378**	**0.378**	**0.378**	**0.378**
		Power cost per ton, US$	**0**	**1.89**	**3.78**	**5.67**	**7.56**	**9.45**	**11.34**
		Total Input Cost, US$	**1.21758**	**3.10758**	**4.99758**	**6.88758**	**8.77758**	**10.6676**	**12.5576**
Output Element		**-150 µm discharge, %**	**50.12**	**50.12**	**50.12**	**50.12**	**50.12**	**50.12**	**50.12**
		Total Input cost per -150 µm discharge, US$/%	**0.02429**	**0.062**	**0.09971**	**0.13742**	**0.17513**	**0.21284**	**0.25055**
Trade off		**Total Input cost per -150 µm discharge Variance (Trade Off), US$/%**	**0.0085**	**0.0065**	**0.00451**	**0.00251**	**0.00052**	**-0.00148**	**-0.00347**
		Percentage Variance (Trade Off), %	**0.850**	**0.650**	**0.451**	**0.251**	**0.052**	**-0.148**	**-0.347**

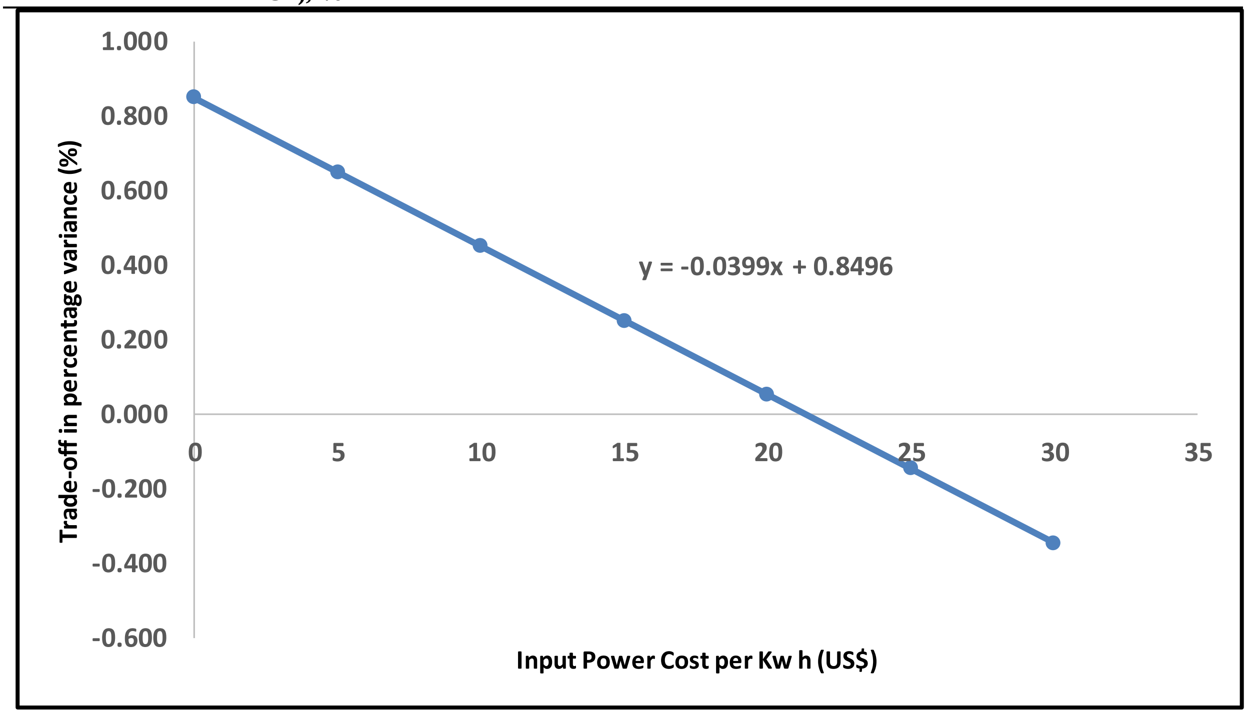

Figure 1. Trade-off relationship with variable power prices

Table 6. Trade-off at variable prices for Company 1 steel ball brand input

		Peroids	1	2	3	4	5	6	7
Input Element	Company 1 Forged Steel Ball	**Power cost per Kwh, US$**	**0.18**	**0.18**	**0.18**	**0.18**	**0.18**	**0.18**	**0.18**
		Changes in Unit cost per ton of Steel Ball, US$	**500**	**700**	**900**	**1100**	**1300**	**1500**	**1700**
		Steel Ball consumption, Kg/t	**1.31**	**1.31**	**1.31**	**1.31**	**1.31**	**1.31**	**1.31**
		Steel Ball consumption cost, US$	**0.655**	**0.917**	**1.179**	**1.441**	**1.703**	**1.965**	**2.227**
		Power usage per ton, Kwh/t	**0.353**	**0.353**	**0.353**	**0.353**	**0.353**	**0.353**	**0.353**
		Power cost per ton, US$	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**
		Total Input Cost, US$	**0.719**	**0.981**	**1.243**	**1.505**	**1.767**	**2.029**	**2.291**
Output Element		**-150 µm discharge, %**	**49.42**	**49.42**	**49.42**	**49.42**	**49.42**	**49.42**	**49.42**
		Total Input cost per -150 µm discharge, US$/%	**0.0145**	**0.0198**	**0.0251**	**0.0304**	**0.0357**	**0.0410**	**0.0463**
Input Element	Company 2 Forged Steel Ball	**Unit cost per ton of Steel Ball, US$**	**1338**	**1338**	**1338**	**1338**	**1338**	**1338**	**1338**
		Steel Ball consumption, Kg/t	**0.91**	**0.91**	**0.91**	**0.91**	**0.91**	**0.91**	**0.91**
		Steel Ball consumption cost, US$	**1.2176**	**1.2176**	**1.2176**	**1.2176**	**1.2176**	**1.2176**	**1.2176**
		Power usage per ton, Kwh/t	**0.378**	**0.378**	**0.378**	**0.378**	**0.378**	**0.378**	**0.378**
		Power cost per ton, US$	**0.068**	**0.068**	**0.068**	**0.068**	**0.068**	**0.068**	**0.068**
		Total Input Cost, US$	**1.286**	**1.286**	**1.286**	**1.286**	**1.286**	**1.286**	**1.286**
Output Element		**-150 µm discharge, %**	**50.12**	**50.12**	**50.12**	**50.12**	**50.12**	**50.12**	**50.12**
		Total Input cost per -150 µm discharge, US$/%	**0.026**	**0.026**	**0.026**	**0.026**	**0.026**	**0.026**	**0.026**
Trade off		**Total Input cost per -150 µm discharge Variance (Trade Off), US$/%**	**0.011**	**0.006**	**0.001**	**-0.005**	**-0.010**	**-0.015**	**-0.021**
		Percentage Variance (Trade Off), %	**1.111**	**0.581**	**0.051**	**-0.479**	**-1.009**	**-1.540**	**-2.070**

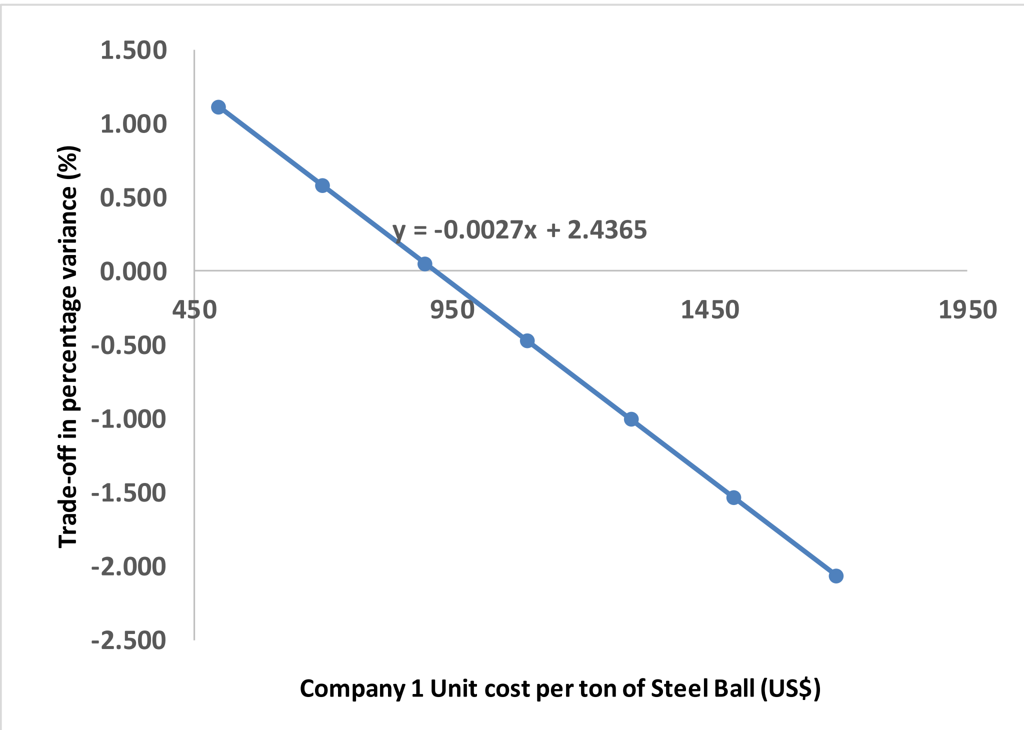

Figure 2. Trade-off relationship with variable Company 1 steel ball brand

Table 7. Trade-off at variable prices for Company 2 steel ball brand input

		Periods	1	2	3	4	5	6	7
Input Element		**Power cost per Kwh, US$**	**0.18**	**0.18**	**0.18**	**0.18**	**0.18**	**0.18**	**0.18**
	Company 1 Forged Steel Ball	**Changes in Unit cost per ton of Steel Ball, US$**	**1237**	**1237**	**1237**	**1237**	**1237**	**1237**	**1237**
		Steel Ball consumption, Kg/t	**1.31**	**1.31**	**1.31**	**1.31**	**1.31**	**1.31**	**1.31**
		Steel Ball consumption cost, US$	**1.6205**	**1.6205**	**1.6205**	**1.6205**	**1.6205**	**1.6205**	**1.62047**
		Power usage per ton, Kwh/t	**0.353**	**0.353**	**0.353**	**0.353**	**0.353**	**0.353**	**0.353**
		Power cost per ton, US$	**0.0635**	**0.0635**	**0.0635**	**0.0635**	**0.0635**	**0.0635**	**0.06354**
		Total Input Cost, US$	**1.684**	**1.684**	**1.684**	**1.684**	**1.684**	**1.684**	**1.68401**
Output Element		**-150 µm discharge, %**	**49.42**	**49.42**	**49.42**	**49.42**	**49.42**	**49.42**	**49.42**
		Total Input cost per -150 µm discharge, US$/%	**0.0341**	**0.0341**	**0.0341**	**0.0341**	**0.0341**	**0.0341**	**0.03408**
Input Element	**Company 2 Forged Steel Ball**	**Changes in Unit cost per ton of Steel Ball, US$**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**	**1900**
		Steel Ball consumption, Kg/t	**0.91**	**0.91**	**0.91**	**0.91**	**0.91**	**0.91**	**0.91**
		Steel Ball consumption cost, US$	**1.183**	**1.274**	**1.365**	**1.456**	**1.547**	**1.638**	**1.729**
		Power usage per ton, Kwh/t	**0.378**	**0.378**	**0.378**	**0.378**	**0.378**	**0.378**	**0.378**
		Power cost per ton, US$	**0.068**	**0.068**	**0.068**	**0.068**	**0.068**	**0.068**	**0.06804**
		Total Input Cost, US$	**1.251**	**1.342**	**1.433**	**1.524**	**1.615**	**1.706**	**1.79704**
Output Element		**-150 µm discharge, %**	**50.12**	**50.12**	**50.12**	**50.12**	**50.12**	**50.12**	**50.12**
		Total Input cost per -150 µm discharge, US$/%	**0.02496**	**0.02678**	**0.02859**	**0.03041**	**0.03222**	**0.03404**	**0.03585**
Trade-off		**Total Input cost per -150 µm discharge Variance (Trade Off), US$/%**	**0.00911**	**0.00730**	**0.00548**	**0.00367**	**0.00185**	**0.00004**	**-0.00178**
		Percentage Variance (Trade Off), %	**0.91146**	**0.72989**	**0.54833**	**0.36677**	**0.18520**	**0.00364**	**-0.17793**

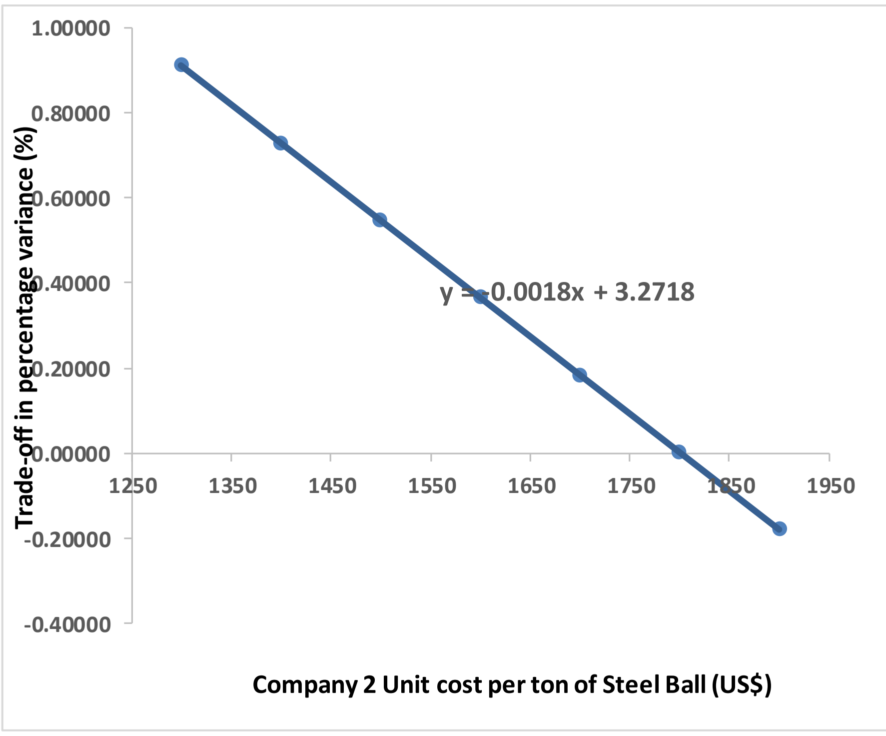

Figure 3. Trade-off relationship with variable Company 2 steel ball brand

5. Conclusion and Recommendation

Trade-off has been decisive factor for detecting the focus of a given enterprise towards the achievement set goals of overcoming situations of compromising efficiency by trying to maximize profit under pretext of cheap price (Johnson, 2005; Hill, 2015). The quantitative analysis in this research was to test the two different brands of steel balls and their corresponding index numbers of the discharge product variables as a model for trade-off evaluation. The study illustrated the evaluations of power usage, steel ball consumption rate and resultant effects of the two different steel ball brands on the discharge product particle size fractions. From the data analysis, 49.42% particle size fraction passing 150 µm by using company 1 steel ball brand as compared to 50.12% particle size fraction passing 150 µm by using company 2 steel ball brand. Again, deduction from the total input cost per percentage passing 150 µm for company 1 and 2 steel balls were US$0.034/% and US$0.026/% respectively. Hence, percentage variance of 0.8% between total input cost per percentage passing 150 µm (-150 µm discharge) indicates the trade-off resulting from preferring one product (i.e. Company 1 or 2 steel balls) against the other. Application of the trade-off of 0.80% percentage variance, amount to cost saving of US$480.00 per day which will be equal to US$175349.65 per year upon using company 2 steel ball brand instead of company 1 steel balls for milling. Rationally, the research pointed out the shortfall of accepting input reagent (steel ball) of a production system on only the unit price or consumption rate variance between different items. The limitation of the research is the manual component of evaluating the size fractions of mill feed and discharge samples. Therefore, at the current conditions of unit price, it is recommendable and cost effective to use company 2 steel ball brand as compared to the company 1 steel ball brand. Again, by evaluating changes in price of power and the steel ball brands, company 2 steel ball should be preferred at unit cost of power lower than US$21.29 and at unit prices lower than US$1817.67per ton for company 2 steel ball brand. Also, further study using alternative method is recommended to enhance the prepositions made in this research work.

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