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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
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Report of Investigations 9653

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

h	hour	mt/h	metric ton per hour
Lm^3	loose cubic meter	st	short ton
m	meter	$	dollar
mt	metric ton	%	percent
mt/d	metric ton per day		

ECONOMICS OF SAFETY AT SURFACE MINE SPOIL PILES

By Thomas W. Camm[1]

ABSTRACT

This study was done to evaluate the costs of various dumping operations at waste and spoil piles. It has been theorized that accidents associated with dumping operations might be reduced by short-dumping rather than edge-dumping, but many operators have been reluctant to use short-dumping because they believe it is not as cost effective as edge-dumping. To evaluate this perception, researchers at the Spokane Research Laboratory of the National Institute for Occupational Safety and Health reviewed the costs of various dumping methods at waste and spoil piles. The study found that overall cost differences between the two methods were not significant in most cases. However, while overall cost differences between the two methods appear small, capital costs could be more significant when short-dumping if numerous dump sites are used concurrently. The choice of which method to use should be based on considerations of the safety of dozer and truck operators.

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INTRODUCTION

Powered haulage is a major contributor to fatalities at all mining operations and is one of the top five sources of injuries at surface mines. This study is one task in a larger project to investigate ways to reduce hazards from surface mine haulage equipment being conducted at the Spokane Research Laboratory (SRL) of the National Institute for Occupational Safety and Health. As part of the project, a cost modeling approach was undertaken to study the economic effects of injury prevention as a useful tool for promoting public health.

BACKGROUND

Typically, when mine haulage trucks dump waste rock or overburden at a spoil pile, the trucks are backed up to a berm at the edge of the pile and the material is dumped over the edge (edge-dumping, also called end-dumping or berm-dumping) (figure 1). An alternative used less frequently is to dump the material back from the edge of the spoil pile and push the material over the edge with a dozer (short-dumping, also referred to as plug-dumping, back-dumping, or butt-dumping) (figure 2).

The main consideration in the edge-dumping method is reduction in the amount of dozer work required. Often, a rubber-tired dozer is of sufficient size to maintain the berm adequately. At smaller operations where haulage distances are short, a rubber-tired dozer can sometimes split time between maintaining the spoil pile and performing cleanup duties at the shovel. This split duty is less likely if the mine is short-dumping because of the added time required for the dozer to be at the spoil pile.

Initially, it was thought there would be a time savings in truck cycle time at a dump site if short-dumping was used instead of edge-dumping. However, site visits and discussions with engineers at various mines indicated that there was little difference in cycle times because in most instances, the dumping phase was a small segment of a truck's cycle time.

Figure 1.—Edge-dumping.

Figure 2.—Short-dumping.

OVERVIEW OF DUMP-SITE INJURIES

The potential for dump-site injuries exists at any mine. Whether dump sites are temporary materials stockpiles or semipermanent or permanent spoil piles, mobile mining equipment is used extensively in elevated areas near dumping points (May 1990). Dumping over an edge is considered the most efficient means of handling material at many sites. For this reason, dumping over an edge is widely practiced. However, injury data suggest that the practice of end-dumping has a significant degree of risk associated with it. Krowczyk (1995) noted that between 1991 and 1994, the operation of a haulage truck accounted for 26 fatalities, which was 27.7% of the total number of fatalities at surface mines. A sizeable proportion of these fatalities related to a truck's rolling off a bench, highwall, or roadway. May noted also that from 1983 to 1987, haulage trucks were implicated in 80% of all dumping point injuries, resulting in seven fatalities and 61 lost-workday injuries.

As a follow-up to the work done by May, NIOSH researchers examined haulage truck dump-site injuries using Mine Safety and Health Administration (MSHA) accident data. A subset of injury data for the period 1988 through 1997 was identified for coal and metal/nonmetal mines. The set included 370 lost-time injuries and fatalities involving haulage trucks working at a dump site. Narratives were analyzed for each injury, and a coding scheme was developed that included the activity, result, and factors contributing to the injury. An outline of the key findings involving injuries to personnel is given below.[2]

Of the 370 haulage truck incidents, 26 resulted in fatalities, and 5 resulted in permanent disabilities. Thirty-three were classified as lost-day and restricted-activity injuries. Three-hundred and six injuries were classified as days away from work only.

- Incident type: Trucks falling over edge = 3; truck rollovers on same level = 93; truck bounced or shaken = 78; collisions = 12; trucks hung up on edge = 10; contact with power line = 3; unknown/other = 23.
- Mine category: 133 bituminous coal, 180 stone, 66 metal, 46 sand and gravel, 17 nonmetal, and 8 anthracite coal.
- Truck activity: 179 dumping but not moving, 156 backing up, 32 moving forward, 3 unknown or other.
- Effect on operator: 200 thrown into object, 80 jarred or tossed about, 52 thrown from cab, 16 suffered musculoskeletal injury, 8 struck by object, 8 burned, 4 drowned, 2 electrocuted.

[2]This injury section is adapted from an unpublished report entitled "Haulage Truck Dump Site Safety: An Examination of Reported Injuries," by Fred Turin and William Wiehagan, industrial engineers at the Pittsburgh Research Laboratory, prepared in conjunction with the study presented here.

COSTS OF INJURY

Workplace injuries in the United States were estimated by Miller and Galbraith (1995) to cost $140 billion annually (December 1990 dollars). Fatal injuries were only 0.1% of the total number of cases, but were 20.5% of total costs. Also of note, nonfatal, compensable lost-work accidents were 20.9% of the cases and 73.8% of the total costs. In 1992, workplace injuries (fatal plus nonfatal) in the United States cost $145.37 billion (Leigh et al. 1997).

Employer costs are only part of the total. Leigh et al. (1997) described direct costs as including actual dollars spent on providing health care, property damage, police and fire services, and insurance administration expenses. Indirect costs to the worker included lost earnings, lost home production, and lost fringe benefits. Indirect costs to employers included costs associated with retraining and restaffing, coworker costs of lost or lowered productivity, and time delays. While direct costs canbe substantial, they only represent about 34% of total costs, with indirect costs contributing 66% of the total (Leigh et al. 1996). Table 1 is a summary of direct and indirect cost categories.

A fatal injury has an average cost of $2.57 million and a nonfatal compensable injury $46,400 (Miller and Galbraith 1995; Miller 1997). Viscusi (1996) estimates the cost of a fatality at $5 million. The costs based on Miller and Galbraith (1995) are listed by category in table 2. A large proportion of the cost of fatality is quality of life at $1.9 million. Quality of life is calculated based on estimates of the wage premiums paid to compensate workers for taking risky jobs. The average used by Miller and Galbraith was $24 in after-tax wage compensation per a 1-in-100,000 chance of being killed on the job during the year. The quality-of-life estimated cost of $1.9 million was computed by subtracting the values in the other cost categories (medical, wages, fringe benefits, and household work) from the wage compensation per fatality.

Medical and emergency services costs are based on data from the government's annual reports on total workers' compensation medical payments. Wages and fringe benefits losses for fatalities were computed at a 4% discount rate. For

Table 1.—Direct and indirect cost categories (adapted from Leigh et al. 1996).

Direct costs	Indirect costs
Medical	Lost earnings
Administrative:	Lost fringe benefits
Workers' compensation	Lost home production
Private insurance	Workplace training, restaffing, distribution
Medicaid	Time delays
Medicare	Injuries to innocent third parties
Welfare	
Indemnity administrative:	
Workers' compensation	
Private insurance	
Social Security	
Property damage	
Police and fire service	
Injuries to innocent third parties	

Table 2.—Costs per injury by severity, December 1990 dollars (adapted from Miller and Galbraith 1995)

Cost category	Fatal	Nonfatal compensable
Medical/emergency services	13,000	6,300
Wages/fringe benefits	520,000	15,000
Household work disruption	110,000	2,500
Work disruption	9,900	2,500
Legal and administrative	18,000	2,100
Subtotal	670,900	28,400
Quality of life	1,900,000	18,000
Total	2,570,900	46,400

costs of injuries, workers' compensation data were used. Household work loss was estimated on the basis of $0.214 in lost household production for each dollar of wage loss. This took into account reduced wages from workers' compensation, sick leave, and lost fringe benefits. Workplace disruption and employer productivity loss costs included supervisor's time spent in dealing with the incident. In addition, a fatal injury costs 4 months of productivity (wages plus fringe benefits) due to recruitment, retraining, and lost special skills. A compensable lost-time work injury cost 1 month of productivity. Legal and administrative costs were computed using multipliers for health insurance, life and disability insurance, workers' compensation, auto liability insurance, auto property damage insurance, and sick leave. These costs are summarized in table 2 (Miller and Galbraith 1995:December 1990 dollars).

CONSIDERATIONS FOR CHOOSING A DUMPING METHOD

Edge-dumping is favored by mine operators because it is the simplest method—just back a truck up to a berm and dump. Most of the material falls over the edge, so there is a minimal amount of dozer work required to maintain the berm. Consequently, the effective life of the dozer is longer because the dozer is used less.

With edge-dumping, the material is basically in place and only needs to be sculpted to maintain the berm. This requires that only 20% to 50% of the material needs to be moved by the dozer, and this for only a very short distance. This situation contrasts with short-dumping, where 100% of the material must be moved by dozer. Because material is dumped back from the edge, it must be moved a greater distance than edge-dumped material. Thus, short-dumping requires more material to be moved over a greater distance than does edge-dumping.

There are, however, circumstances where short-dumping is preferred. In three situations in particular, short-dumping is strongly advisable for safety reasons. The first is when the spoil pile has been loaded out. This occurs when material has been removed from the lower part of the slope of the spoil pile, causing a steep wall that exceeds the natural angle of repose of the material. The main danger in this situation is that the added weight of a loaded truck at the upper edge of the pile could cause the wall to collapse. If the truck falls over the edge, the driver is likely to be injured, and any machine or worker at the bottom may be buried by collapsing material.

The second situation is when there are cracks in the edge of the pile. The presence of cracks increases the likelihood that the edge will collapse if any weight is added. Figure 3 shows

Figure 3.—Cracks near berm of spoil pile can create hazards for trucks dumping material near edge.

an edge with cracks. It is best to use a dozer to push more material over the edge to stabilize the spoil pile before any other equipment is allowed near the edge.

The third circumstance where edge-dumping should be avoided is when the berm along the edge is too low. To avoid having the truck go through the berm and over the edge when dumping, the berm should be at least the height of the axle of the largest piece of equipment dumping at the berm. The main function of the dozer during edge-dumping is to ensure that the berm is adequately maintained.

COST MODELING

There are several approaches available for cost modeling, and which one is chosen depends primarily on the level of detailed information available, the precision required for costs, and the amount of time and personnel available to perform a cost analysis. The general approach for prefeasibility studies is to use generalized cost equations with limited design variables. These equations are most commonly a geometric regression equation in the form $y = ax^b$, where y is the cost, a and b are constants, and x is the design variable (tons per day, for example). This type of approach is most useful for calculating the overall cost of a mine in a short amount of time with limited engineering design required (Camm 1991; O'Hara and Suboleski 1992; Schumacher 1997).

A more detailed approach involves a specific engineering design that itemizes the particular requirements of each unit process in the mine. This includes estimating specific labor requirements, types of supplies and their consumption amounts per day (or per ton), and equipment (type, size, number of each) and its utilization. Using all these detailed items and amounts, a more specific (and accurate) cost estimate is calculated. Case studies of actual mining operations with characteristics similar to the mine being evaluated can provide guidance in developing engineering designs (Camm 1995; Gentry and O'Neil 1984).

A cost-modeling approach to studying the economic effects of injury prevention provides a useful tool for promoting public health. It puts the cost of safety, and perhaps more importantly, the cost (and consequences) of minimizing or ignoring safety, into terms that will get the attention of decision makers. While the concept of worker safety is readily agreed upon by most people, in practice it often is sublimated to perceived economic expediencies. By demonstrating that injury prevention not only makes good social and public relations sense, but is also good economic sense, there is increased likelihood that new approaches to injury prevention will be embraced with more enthusiasm.

COST CATEGORIES

The cost of operating a dozer at a dump site is the main variable to consider when comparing edge-dumping and short-dumping. These costs can be divided into two broad categories, labor and equipment.

Labor costs depend on numerous factors: geographic location, availability of experienced workers, commodity being mined, size of the mine, unionized or nonunionized labor, use or nonuse of contractors, and size of the corporation operating the mine. Hourly wages paid to an equipment operator are usually considered a direct operating cost (Gentry and O'Neil 1984; Humphreys 1991).

Added to the direct costs of wages is the wage (or labor) burden. This factor includes insurance, Social Security taxes (FICA), unemployment tax, and other expenses that are based on hourly wages. Table 3 provides a summary of the typical items included in labor calculations. The wage burden can add from 25% to 58% to labor costs at surface coal mines in the western United States (Schumacher 1998).

Indirect labor costs include maintenance, supervision, support services, administration, and overhead.

Equipment costs can be broadly divided into two categories, operating cost and capital cost (Camm 1994b; Gentry and O'Neil 1984; Humphreys 1991; Schumacher 1996). Operating costs include what is consumed or used during actual operation of equipment. Replacement and repair of parts during normal operation of equipment, diesel fuel, lubrication, tires, and maintenance labor costs are all included in equipment operating costs. These costs are expressed in dollars per hour of equipment operation, dollars per ton of ore mined, or dollars per day.

Table 3.—Breakdown of labor expenses (adapted from Schumacher 1998; Pruitt 1998)

Federal:		
Social Security (FICA)	6.2% of wages less than $68,400	
Medicare	1.45% of all wages	
Unemployment tax (FUTA)	6.2% of wages less than $7,000	
	0.8% of wages less than $7,000[1]	
Black lung insurance	$500 lump sum annually	
State (varies by state. Wyoming is used as an example below.):		
Unemployment insurance	0.30-8.80% of wages less than $12,500	
Workers compensation	$0.91 per $100 of all wages	
Other misc. (Federal, state, or local)	Varies	
Company (dollars per month, varies by company):		
Medical insurance	$300	
Dental insurance	(included in medical)	
Vision insurance	(included in medical)	
Disability insurance	$50	
Life insurance	$20	
Black lung insurance	$20	
Auto liability insurance	$20	
Excess liability insurance	$20	
Total insurance		$430
Company retirement contribution	0-10% of all wages	
Other miscellaneous	Varies	
Paid leave (typical range, days per year):		
Holidays	10-12	
Vacation	10-25 (depending on length of service)	
Sick leave	0-10	
Total leave		20-47

TOTAL BURDEN (for surface coal, western United States) 25-58%, average 40% nonunion, 43% union.

[1]Tax rate is 6.2%; a credit up to 5.4% can be taken for state unemployment taxes paid. If the full 5.4% state credit is taken, the effective Federal rate is 0.8%.

COST ANALYSIS

Overall operating costs typical for surface mines are summarized in table 4. These are direct mine operating costs and do not include administrative, infrastructure, corporate overhead, or mineral processing costs. Depending on the cost estimation system used and the tonnage of material moved, total operating mining costs for a surface operation can vary from $0.96 to $1.46 per ton of material moved. Costs are adjusted to 1998 dollars using Mining Cost Service indexes (Schumacher 1999).

The choice of which earthmoving machine to use at a dump site will depend on the amount of material that must be moved. The most common dozer sizes found at operating mines are Caterpillar's D10 or D11 (or an equivalent machine). At sites with less capacity requirements and where the dozer is used to clean up away from the dump as well as to maintain the dump site, rubber-tired dozers are often used. Using data from the Caterpillar Performance Handbook (Caterpillar 1996) the capacities of D10, D11, and 834D dozers over distances of 15 and 30 m are summarized in table 5.

Table 4.—Operating costs for surface mines calculated using various cost models, dollars per metric ton of material moved (all costs adjusted to 1998 dollars)

Cost model	Ore production, mt/d		
	10,000	20,000	40,000
Camm (1991)	1.43	1.29	1.17
Camm (1994a)	1.46	1.30	1.16
Schumacher (1997)	1.21	1.12	0.96

NOTE: All costs based on a stripping ratio of 2:1. Details of cost equations appear in appendix.

In many cases, a mine will be able to switch to short-dumping using existing equipment. For example, if a mine used a D11 dozer and produced 40,000 mt/d of waste, then it could meet the requirements for edge-dumping (table 5). Assuming that short-dumping would require 15 m of dozing distance, the D11 is still adequate to meet the needs of the mine. Table 6 indicates that operating costs for a dozing distance of 15 to 30 m would increase by $0.011/mt of waste material moved on the spoil pile. Based on a typical direct mine operating cost of $1.10/mt of material moved by edge-dumping, short-dumping would increase costs by $0.01/mt, an increase of 0.9%. A constant labor wage for the dozer operator of $19.49/h is used in table 6. The wage burden would add 40% ($7.80/h), for a total labor cost of $27.29/h. Equipment costs are compared for three common dozer sizes: a large rubber-tired dozer (equivalent to a Caterpillar model 834B) and two track-type dozers (equivalent to Caterpillar models D10 and D11).

For comparative purposes, the costs in table 6 are given for surface mines having a stripping ratio of 2:1 and average dozing distances of 15 m for edge-dumping and 30 m for short-dumping. Capital costs for minerals extraction at a surface mine (excluding infrastructure and minerals processing) are $24 million, $53 million, and $94 million for production capacities of 10,000, 20,000 and 40,000 mt/d of ore, respectively, in 1998 dollars (Schumacher 1996). The appendix contains details of individual cost calculations.

Depreciation schedules are set by the Internal Revenue Service at a fixed rate over 7 years for mobile mining equipment (Internal Revenue Service 1998). Whether the equipment is used constantly or for only a few hours a day, depreciation is the same for tax purposes.

Estimated capital costs for dozers are $584,000 for a 834B (rubber-tired), $790,000 for a D10, and $1,216,000 for a D11 (both the D10 and the D11 are track-type machines) (Schumacher 1996). Unit costs are estimated based on published sources and represent typical costs.

Equipment purchase costs and operating costs (table 6) can vary markedly from mine to mine, depending on geographic location and the corresponding availability of experienced labor; size of mine; use of union or nonunion labor; size, type, and age of equipment; and effectiveness of equipment maintenance program. Because of this variability, costs used here should be considered only as illustrative of the modeling process. Any actual mine is going to have specific labor wages, labor burdens, and equipment costs unique to its operation.

As an example, a mine that extracts 20,000 mt of ore per day and has a stripping ratio of 2:1 will produce 40,000 mt of waste per day. Using edge-dumping and assuming only 20% of the material needed to be moved, a dozer should be able to move an average of 8,000 mt/d for a distance of 15 m. All three of the dozers in table 5 could handle this requirement. If the mine used short-dumping, all 40,000 mt of waste per day would need to be moved an average distance of 30 m. Based on the information in table 5, a D11 would probably be necessary. Actual operating costs per ton moved would decrease because of the increased efficiency of a D11. However, because more material is being moved, operating costs per day would increase by $624/d (8,000 mt/d × $0.047/mt = $376/d versus 40,000 mt/d × $0.025/mt = $1,000/d).

Based on a mining cost of $1.10/mt of material moved and 60,000 mt of ore and waste mined per day, the estimated daily operating cost is $66,000/d. The $624/d is slightly less

Table 5.—Estimated dozer production capacities

Dozer model	Av. dozing distance, m	[1]Lm^3/h	Material moved, mt/h	[2] Daily capacity, mt/d
D10	15	2,600	3,640	49,500
	30	1,500	2,100	28,500
D11	15	4,000	5,600	76,100
	30	2,200	3,080	41,800
834D	15	1,100	1,540	20,900
	30	650	910	12,300

[1]Lm^3 = Loose cubic meters. This term refers to material that has been excavated and therefore is less dense than its equivalent volume in the ground.

[2]Based on 1.4 Lm^3/h, 85% equipment availability, two 8-h shifts per day. (Source: Caterpillar 1996)

Table 6.—Estimated operating dozer costs

Dozer model	Av. dozing distance, m	Operating cost, $/h	Material moved, mt/h	Operating costs, $/mt
D10	15	$62.24	3,460	$0.017
	30	62.24	2,100	0.030
D11	15	78.27	5,600	0.014
	30	78.27	3,080	0.025
834D	15	71.68	1,540	0.047
	30	71.68	910	0.079

NOTE: All costs in 1998 dollars. Based on Schumacher 1996.

than a 1% increase in daily mine operating costs. The increase in capital costs for a D11 over an 834D is $632,000 ($1,216,000 to $584,000). The estimated capital cost for a 20,000-mt/d surface mine is $52 million, which is an increase of 1.2%.

If nonroutine costs were included, such as for repairing a truck that has fallen over an edge, for loss of use of that truck, and for the use of equipment needed to free a truck after it has been stuck, then the cost difference between the two methods would be reduced further.

SUMMARY

There were 370 lost-time accidents involving haulage trucks at mine dump sites between 1988 and 1997. One-hundred thirty-seven involved trucks falling over an edge. According to Miller (1997), the direct cost of a fatality to an employer is $9,900 and the cost of a lost workday injury is $1,600. Direct employer costs of fatalities or injuries are a small proportion of total costs. According to Miller and Galbraith (1995), the total cost of a fatality can be $2,590,900 and the cost of a nonfatal work injury $46,400.

Edge-dumping is the most common method for dumping waste at mine spoil piles. Short-dumping is usually employed when there is a safety concern about edge-dumping. The added cost of short-dumping can be quite variable depending on the circumstances. In test calculations, short-dumping added about 1% to both mine operating and capital costs. The largest cost difference was seen when a rubber-tired dozer was initially used for both edge-dumping at the spoil pile and for other duties, such as shovel clean-up, and it became necessary to switch to short-dumping, which required a larger track-type dozer to be used at the spoil pile full-time.

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APPENDIX—MINE OPERATING AND CAPITAL COSTS

Cost indexes

All costs are updated to 1998 dollars using Mining Cost Service indexes for surface mines (Schumacher 1999).

Year	Cost index
1989	90.4
1991	97.7
1996	105.7
1998	106.9

Camm 1991:

$5.14(X)^{-0.148}$, where X = short tons of material mined (ore + waste) for a 2:1 stripping ratio and production of 11,023, 22,046, and 44,092 st (10,000, 20,000, and 40,000 mt) of ore per day.

1989 dollars:

10,000 $5.14(11{,}023 \times 3)^{-0.148}$ = \$1.10/st material
20,000 $5.14(22{,}046 \times 3)^{-0.148}$ = \$0.99/st material
40,000 $5.14(44{,}092 \times 3)^{-0.148}$ = \$0.90/st material

Updated to 1998 dollars and converted to dollars per metric ton (dollars per short ton ÷ 0.9072):

10,000 1.10 × (106.9/90.4)/0.9072 = \$1.43/mt material
20,000 0.99 × (106.9/90.4)/0.9072 = \$1.29/mt material
40,000 0.90 × (106.9/90.4)/0.9072 = \$1.17/mt material

Camm 1994a

$[6.725(X)^{-0.165}](SR+1)^{0.835}$, where X = short tons of ore and SR = stripping ratio for a 2:1 stripping ratio and production of 11,023, 22,046, and 44,092 st (10,000, 20,000, and 40,000 mt) of ore per day.

1991 dollars:

10,000 $[6.725(11{,}023)^{-0.165}](2+1)^{0.835}$ = \$3.62/st ore, 3.62/(SR+1) = \$1.21/st material
20,000 $[6.725(22{,}046)^{-0.165}](2+1)^{0.835}$ = \$3.23/st ore, 3.23/(SR+1) = \$1.08/st material
40,000 $[6.725(44{,}092)^{-0.165}](2+1)^{0.835}$ = \$2.88/st ore, 2.88/(SR+1) = \$0.96/st material

Updated to 1998 dollars and converted to dollars per metric ton:

10,000 1.21 × (106.9/97.7)/0.9072 = \$1.46/mt material
20,000 1.08 × (106.9/97.7)/0.9072 = \$1.30/mt material
40,000 0.96 × (106.9/97.7)/0.9072 = \$1.16/mt material

Schumacher (1997)

For a 2:1 stripping ratio and production of 10,000, 20,000, and 40,000 mt of ore per day.

1996 dollars:

10,000 \$3.63/mt ore, 3.63/(SR+1) = \$1.21/mt material
20,000 \$3.36/mt ore, 3.36/(SR+1) = \$1.12/mt material
40,000 \$2.88/mt ore, 2.88/(SR+1) = \$0.96/mt material

Updated to 1998 dollars:

10,000 1.21 × (106.9/105.7) = \$1.22/mt material
20,000 1.12 × (106.9/105.7) = \$1.13/mt material
30,000 0.96 × (106.9/105.7) = \$0.97/mt material

To receive other information about occupational safety and health problems, call
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