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A CASE STUDY ON IMPROVING LOGISTICS BY USING VENDING MACHINES FOR SUPPLYING PERSONAL PROTECTION ITEMS IN MINING OPERATIONS

Prof. Juan Sepúlveda Salas
University of Santiago of Chile
PhD. Eng. Sciences, The University of Tennessee, Knoxville, United States
Department of Industrial Engineering, University of Santiago of Chile
Ecuador 3769, Estación Central
Santiago, Chile
juan.sepulveda@usach.cl

Prof[a]. Felisa Córdova Gonzalez
University of Santiago of Chile
Dr. Ing. Informatique, Université de Paris XI, Paris, France
Department of Industrial Engineering, University of Santiago of Chile
Ecuador 3769, Estación Central
Santiago, Chile
felisa.cordova@usach.cl

Claudio Benítez Valenzuela
Compañía Minera Doña Inés de Collahuasi
Lic. Industrial Engineer, Arturo Prat University, Iquique
Superintendency of Supply
Baquedano 902
Iquique, Chile
cbenitez@collahuasi.cl

Rodrigo A. Yañez Alonso
Compañía Minera Doña Inés de Collahuasi
Lic. Industrial Engineer, Adolfo Ibañez University, Santiago
Superintendency of Supply
Baquedano 902
Iquique, Chile
rayanez@collahuasi.cl

Victor Barrientos Berg
Compañía Minera Doña Inés de Collahuasi
Lic. Mechanical Engineer, University of Santiago of Chile
Superintendency of Supply
Baquedano 902
Iquique, Chile
vhbarrientos@collahuasi.cl

ABSTRACT: Personal protection elements (PPE) such as safety glasses, work clothing, ear plugs, are fast-moving, low cost items in most industrial settings for which warehousing and dispatching is required. In some cases, such warehousing is centralized and therefore personnel must deliver in large amounts such elements to workers, thus demanding man hours, space, and transportation for miners and other workers to centralized facilities. Automating the delivery by using vending machine technology located at critical locations is a natural way to deal with the problem. However, the number of machines, locations, replenishment times and quantities, communication links, backup modes, and supplier modes (internal or outsourced) will define different design configurations given the number of alternatives that can arise during conceptual design of the network. In this paper we present a mathematical model for optimizing the logistics costs involving this kind of decisions: such as inventory costs, stock out costs, transportation, and equipment operational costs. An example and numerical analysis is provided.

Keywords: Supply Chain Management; Logistics; Mining Logistics; Inventory Management.

1. INTRODUCTION

In many companies, personal protection elements (PPE) delivery is carried out in a traditional manner by processing user requirements at a centralized warehousing facility. Such facility provides home delivery service normally from eight AM to eight PM all during the year. However, since mining operations are mostly executed three shifts per day, the hourly limitation places a weakness in the quality of service of the logistics department; in practice, the material is picked up before the closing time and it is accumulated in sites with little or no control for later utilization. The use of vending machines (VM) located at selected sites with 24-hours availability and computerized control is naturally a suitable way for dealing with the delivery of these types of items (ear plugs, safety glasses, gloves, mask filters, even work clothes, among others). Besides the improvements in service and efficiency by better control of the inventory, several other advantages can be identified, such as: a) less man-hours dedicated for materials handling and administration at the facility, b) more space available for more expensive items, c) less transportation costs and time needed for workers to move from their working places to the delivery site.

According to (CHOPRA AND MEINDL, 2004) decentralization of the inventory has, as one of its main advantages, the improvement in customer service by closeness to the user and by faster acquisition. On the other hand, inventory maintenance and transportation costs may increase since safety stocks tend to be higher than in the centralized case for the same customer service level (CSL). Besides, materials must be delivered over longer distances. For a discussion on detailed modeling of inventory planning see (SILVER, PIKE AND PETERSON, 1998).

However, when we deal with low-cost items, the effects of centralization in terms of inventory costs tend to diminish and dispatching becomes cumbersome; therefore, their decentralization may be attractive after a cost/benefit (C/B) analysis. Moreover, if the decentralization is supported by automated vending devices (Figure 1) the benefits may be even higher. The C/B analysis may consider savings in man-hours for material handling and paperwork, storage space, operational man-hours and transportation of people towards the warehouse.

In recent years, the increase of demand for metals, such as copper, is calling for companies to raise their production levels and workforce. Thus, a need is created for storing a greater number of higher-value materials, maintenance- repair-operations (MRO) items including PPE. This motivates companies for finding innovative ways for improving storage and delivery.

The paper is organized as follows: in section two the model for representing the supply network of vending machines is presented; in section three an example and analysis of the type of results that the model yields is discussed; finally in section four implementation issues and simulation results are presented.

Figure 1 – View of a vending machine for industrial purposes
Source: http://www.apexindustrial.com

2. MODELING THE LOGISTICS

One of the difficulties to measure the impact of the redesign of the storage and delivery system for PPE is determining the operational costs of the new system. Such costs estimates are necessary in order to justify the project in the mid and long-term. Any alternative for decentralizing inventory handling and delivery must consider costs such as: a) inventory maintenance, b) vending machines (either purchased or rented), c) transportation for replenishing stocks from a central distribution center, and d) other operating expenses (energy, communications, maintenance, etc.)

The main network structure is a long-term decision involving issues such as the location of the distribution center (DC), sites selection for the vending machines, communication links and technology. In the mid and short-term (tactical and operational level) there still remain decisions such as replenishment cycle length, number of vending machines to be used at each location, and vehicle routing for refilling the stock of PPE. Here the number of VM is considered as a mid-term (yearly) decision which depends on the inventory cycle length, that is, the longer the cycle is the greater the number of VM positions will be needed.

In order to estimate the logistic costs, a model is proposed as follows:

Parameters:

μ_{ij} : daily demand of item i in location j, $\forall i = 1..m;\ j = 1..n$

σ_{ij} : std.deviation of the daily demand , $\forall i = 1..m;\ j = 1..n$

p_i : cost of item i in \$/unit, $\forall i = 1..m$

r : anual inventory maintenance rate in %

h_i : holding cost of item i in \$/unit-year, $\forall i = 1..m$

$$h_i = r \cdot p_i$$

f_j : fix transportation cost from DC to location j per trip and vehicle

v_j : variable transportation cost per unit for location $j, \forall j = 1..n$

z_{CSL} : z-level from the std.normal distribution for a given CSL

L : lead time for replenishing VM stock at any location

α : rental and maintenance cost of a VM per year

β : capacity of a VM in units per machine

γ : number of working days per year

Decision variable:

T : cycle length at any location

State variables:

η_j : number of VM at location $j, \forall j = 1..n$

$$\eta_j = (T/\beta) \sum_{i=1}^{m} \mu_{ij} \quad \text{(rounded up to the nearest integer)} \quad (1)$$

TC : average logistic cost per year.

$$TC = \frac{1}{2} \sum_{j=1}^{n} \sum_{i=1}^{m} \mu_{ij} (h_i + 2\frac{\alpha}{\beta})T + \left(\sum_{j=1}^{n} \sum_{i=1}^{m} h_i \sigma_{ij} \right) z\sqrt{T+L} + \gamma \left(\sum_{j=1}^{n} f_j \right) \frac{1}{T} + \gamma \sum_{j=1}^{n} v_j \sum_{i=1}^{m} \mu_{ij} \quad (2)$$

The average cost in (2) contains four parts: the first represents the average inventory costs plus the annual rental cost of VM; the second part accounts for the average cost of the safety stock, which is part of the inventory held in the VM; the third plus the fourth term is the annual transportation cost for replenishing the VM.

Model (2) yields the optimal cycle length T, that is the number of inventory days held at the VM machines.

An assumption of this model is that there exists a common cycle T for all the locations j. The model can be easily modified if a different cycle was needed for each location, as well as if different items were stored at these locations.

Some remarks are pointed out regarding computation of (2):

a) since the cycle T defines the inventory level, including safety stock, the number of positions needed to hold the stock may yield a non-integer number of VM at a location j, as given by (1) ηj must be rounded up to the nearest integer.

b) The value given by (2) represent an upper bound for the annual logistic cost since further improvement can be made by optimizing the routing for each inventory cycle.

As an example of this further improvement consider for instance the network in Figure 2 with distances in Kms.

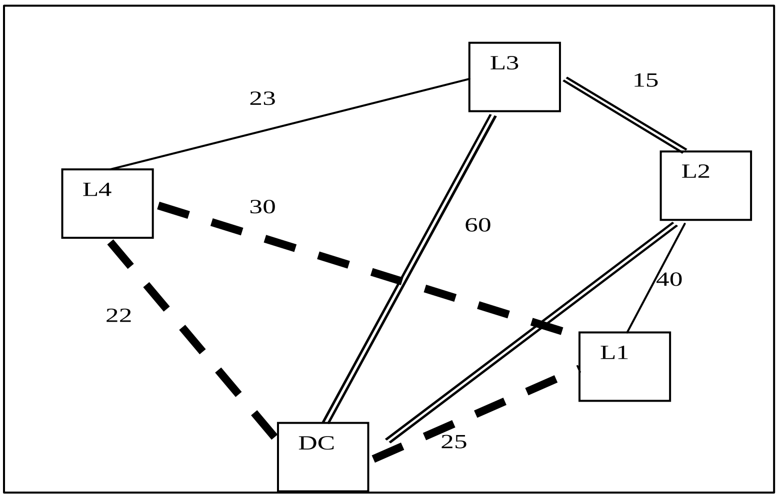

Figure 2 – Example of network of VM machines to be refilled
Source: own elaboration

The number of units to be replenished at each location for a given T cycle (T = 7 days) is shown in Table 1. In Appendix A the data set is shown. A light truck can hold up to 1200 units on each trip.

Table 1 – Example of units to be refilled

Location	Units
L1	525
L2	638
L3	501
L4	518

Source: own elaboration

Although this a very simple example, instead of dispatching one vehicle to each location, a better routing is the one obtained by the Clark & Wright heuristics (CW) as in Table 2 (LAPORTE, 1992). CW is based on the savings of joining locations in a circuit. Routes are shown in dashed and double lines in Figure 2. Specialized software for this problem can also be found in (BALLOU, 2004) and theoretical background of routing in (GENDREAU AND POTVIN, 1998).

Table 2 – Routes by the Clark and Wright heuristics

CW Route	Load	Total distance	Vehicle
CD-L2-L3-DC	1139 units	140 kms.	Truck Nº 1
CD-L1-L4-DC	1043 units	77 kms.	Truck Nº 2

Source: own elaboration

That is, instead of using four vehicles, only two are used. If we consider that for T = 7 there are 52 cycles per year, without improvement the distance per year is 17888 Kms., whereas with CW the value is 11284 Kms., i.e. 37% less.

3. A NUMERICAL EXAMPLE

In "Appendix A" a data set for tactical planning of cycle length T and determination of the number of VM is shown. For this run the parameters in Table 3 are used.

Table 3 – Parameters

z (CSL = 95%)	1.65
L	1
r	25%
$\boldsymbol{\beta}$	588
$\boldsymbol{\alpha}$	8000
f	100
v	0.4
$\boldsymbol{\gamma}$	365

Source: own elaboration

When applying (2) for different T values a series of results can be obtained as shown in Table 4 for T = 7 days of inventory.

Table 4 – Results for T = 7

Main results				**Transportation Cost**	
Location	**Units**	**# VM**	**Yr.Trips**	**Fix**	**Variable**
L1	525	1.0	52.1	5,214	10,950.0
L2	638	2.0	52.1	5,214	13,306.9
L3	501	1.0	52.1	5,214	10,449.4
L4	518	1.0	52.1	5,214	10,804.0

Source: own elaboration

Figure 3 shows a simulation of (2) for values of T from 1 to 26 days. The values are listed in Table 5.

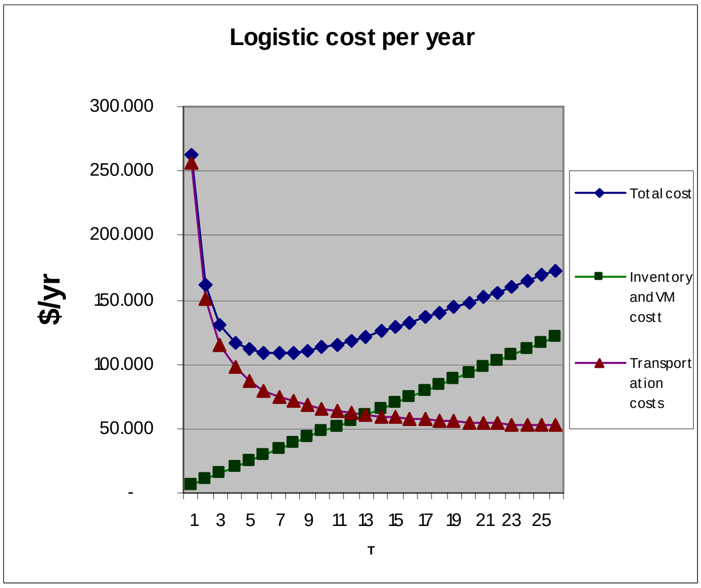

Figure 3 – Curve of the total logistics costs per year
Source: own elaboration

Table 5 – Results for different T values in $/yr.

T	Total Cost	Inv. &VM	Transportation
1	262.558	5.646	256.912
2	160.953	10.379	150.574
3	130.199	15.070	115.129
4	117.141	19.736	97.406
5	111.154	24.382	86.772
6	108.696	29.014	79.683
7	*108.253*	*33.635*	*74.619*
8	109.067	38.246	70.821
9	110.717	42.850	67.867
10	112.951	47.447	65.504
11	115.609	52.038	63.571
12	118.584	56.625	61.960
13	121.803	61.206	60.596
14	125.212	65.784	59.428
15	128.774	70.359	58.415
16	132.459	74.930	57.529
17	136.245	79.498	56.747
18	140.115	84.063	56.052
19	144.056	88.626	55.430
20	148.057	93.187	54.870
21	152.109	97.745	54.364
22	156.205	102.302	53.904
23	160.340	106.856	53.483
24	164.507	111.409	53.098
25	168.704	115.960	52.744
26	172.926	120.510	52.416

Source: own elaboration

The average annual total cost (2) is convex. In the example the minimum cost is at T*=7 days where costs begin to increase due to inventory costs and the rental of VM machines. The longer the inventory cycle is the larger are the inventories and the number of VM to be used.

4. IMPLEMENTATION ISSUES

With the aid of model (2) it is possible to know the number of machines needed for a given demand behavior in the short and mid-term. Besides it can be used to predict the number of VM should an increase in demand take place. Such demand increase may be due, for instance, to a larger workforce to face a production increase in the mid and long-term.

In this work, it has been assumed that the company is in charge of purchasing and supplying the PPE to the vending machines. The company pays for the rental and maintenance of the equipment an annual rate α. Other modes are possible such as a full service under an outsourcing contract where the company only pays by consumption a given amount per year. In the latter mode, the planning decision of inventory and number of VM corresponds to the provider but the model can be used to evaluate the contractor proposal.

Practical and important implementation issues must be considered.

Stock control: In order to control the stock the VM are connected to a data network with proper software to register consumption. This software will alert on extremely low levels of inventory in case that safety stock would not be sufficient.

Consumption control: this control can be facilitated with the VM software by identifying the user and even preventing transaction if an abnormal consumption is taking place. For accessing the VM several devices can be implemented, such as keyed-in personal ID number protected by password, bar code reading, or else, by magnetic card under DEX/UCS standard.

Contingency handling:

a. the first type of contingency is machine failure; for this case a phone or radio service must be provided to alert personnel in charge of the contract and to have the provider to fix the problem.

b. a second contingency is stockout; although safety stock should reduce this event, mechanisms to quickly replenish the stock by sending a vehicle must be present.

c. a third type, is electricity supply failure; here as well as in the other cases above, a certain level of backup stock at the DC should be kept as in the traditional manner.

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Appendix A. Sample data of the example

Loc.	Item	μ	σ	Price	Lot	Avrg. Inv.	Max. Inv.	Yr.Inv. Cost
1	1	5,0	4,4	1,2	10	37,3	42,3	224,0
1	2	5,0	3,5	2,4	10	30,7	35,7	368,6
1	3	4,0	3,9	20	8	32,7	36,7	3.265,9
1	4	3,0	2,2	8,5	6	19,2	22,2	814,6
1	5	1,0	0,5	5	2	4,7	5,7	116,9
1	6	2,0	1,5	14,5	4	13,0	15,0	944,1
1	7	6,0	3,8	12,2	12	33,9	39,9	2.069,4
1	8	8,0	4,5	13	16	41,1	49,1	2.669,4
1	9	10,0	9,8	4	20	82,0	92,0	1.640,3
1	10	6,0	3,3	7,5	12	30,2	36,2	1.134,4
2	1	4,0	3,7	1,2	8	31,2	35,2	187,1
2	2	7,0	4,2	2,4	14	37,9	44,9	454,4
2	3	3,0	1,5	20	6	14,0	17,0	1.402,3
2	4	8,0	5,6	8,5	16	49,2	57,2	2.088,9
2	5	11,0	10	5	22	84,5	95,5	2.112,1
2	6	3,0	2,9	14,5	6	24,3	27,3	1.762,5
2	7	7,0	5	12,2	14	43,7	50,7	2.668,3
2	8	9,0	7,2	13	18	61,9	70,9	4.024,1
2	9	2,0	1,9	4	4	16,0	18,0	319,2
2	10	6,0	4,6	7,5	12	39,8	45,8	1.492,6

Loc.	Item	μ	σ	Price	Lot	Avrg. Inv.	Max. Inv.	Yr.Inv. Cost
3	1	3,0	2	1,2	6	17,7	20,7	106,2
3	2	6,0	5,4	2,4	12	45,7	51,7	548,2
3	3	8,0	6,7	20	16	57,2	65,2	5.723,5
3	4	2,0	1,1	8,5	4	10,1	12,1	428,5
3	5	1,0	0,6	5	2	5,4	6,4	135,2
3	6	4,0	2,7	14,5	8	23,8	27,8	1.728,5
3	7	6,0	4,7	12,2	12	40,5	46,5	2.472,8
3	8	9,0	4,9	13	18	45,0	54,0	2.925,5
3	9	3,0	2,4	4	6	20,6	23,6	412,7
3	10	6,0	4,7	7,5	12	40,5	46,5	1.520,2
4	1	2,0	1,1	1,2	4	10,1	12,1	60,5
4	2	3,0	2	2,4	6	17,7	20,7	212,4
4	3	6,0	4	20	12	35,4	41,4	3.539,4
4	4	9,0	7,6	8,5	18	64,8	73,8	2.756,1
4	5	1,0	0,8	5	2	6,9	7,9	172,0
4	6	4,0	4	14,5	8	33,4	37,4	2.421,1
4	7	3,0	1,6	12,2	6	14,8	17,8	900,2
4	8	5,0	2,7	13	10	24,8	29,8	1.614,7
4	9	7,0	6,9	4	14	57,7	64,7	1.154,1
4	10	10,0	5,2	7,5	20	48,2	58,2	1.808,0