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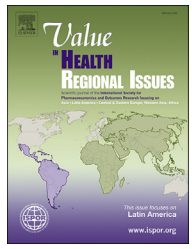

Economic Evaluation

Determining the Operating Costs of a Medical Surveillance Program for Copper Miners Exposed to High Altitude–Induced Chronic Intermittent Hypoxia in Chile Using a Combination of Microcosting and Time-Driven Activity-Based Costing

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A B S T R A C T

Background: Copper mining installations in Chile use a large number of workers who do their jobs at high altitudes, exposing them to the conditions of chronic intermittent hypobaric hypoxia. The Chilean Safety Association implements the surveillance program. **Objective:** This organization, under the sponsorship of the Chilean Superintendency of Social Security, was interested in determining the costs involved in this program to support its decision-making processes and to improve its performance. **Methods:** Direct operating costs of the Hypoxia Medical Surveillance Program were determined through on-site surveys applied to the organization's local agencies in charge. The microcosting method was used, quantifying personnel costs, consumables, and equipment and overhead costs. Time-driven activity-based costing was partially adapted for the allocation of personnel and equipment costs. Costs concerning activities, groups of activities and items, and average cost per exposed worker were determined. **Results:** The annual costs of the program were $127 299.58. The highest costs corresponded to the assessment activities, which were $89 192.13, representing 60.06% of the total. The labor factor costs were $77 568.50, which represents 60.93% of the total. The average cost per worker in the program is $21.17. **Conclusions:** The partial adaptation of the time-driven activity-based costing method in combination with the microcosting method provides a suitable solution to determine the total costs of running a healthcare program of this kind. The information generated by this study will aid in the decision-making and management processes of the Hypoxia Medical Surveillance Program.

Keywords: cost analysis, healthcare costs, microcosting, time-driven activity-based costing

Introduction

In Chile, many copper mining activities take place at a high altitude in the surroundings of the Andes Mountains. Undertaking this work at ≥3000 meters above sea level exposes mine workers to chronic intermittent hypoxia (CIH).

This health condition is characterized by an increase in hematocrit levels, an increase in blood and pulmonary pressure, a high risk of having acute diseases, and deterioration of sleep quality.[1]

The careful and systematic assessment of pre-existing disease factors can mitigate the deterioration in health. Moreover, the design and implementation of medical surveillance programs in several countries form part of the strategies to prevent the negative health conditions for workers exposed to CIH.[2-4]

In line with evidence from scientific studies, regulations issued by the Chilean Ministry of Health establish basic health and environmental conditions in workplaces and health prevention and protection for workers whose job exposes them to CIH. These preventive measures must consider at least promoting health and

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quality of life strategies in a work program, informing the workers about the risks associated with CIH exposure, defining prevention or mitigation measures for the alteration in sleep that can be exacerbated by exposure, and informing the worker about the importance of monitoring the chronic pathology resulting from exposure to CIH.[5-7]

For the prevention, surveillance, and early diagnosis of the effects of CIH exposure, workers must be enrolled in the Occupational Medical Surveillance Program, undergoing periodic and predeparture assessments according to indications in the technical guide prepared by the Department of Occupational Health of the Chilean Ministry of Health, focused mainly on the pathologies associated with this condition.

In this light, the Chilean Safety Association (AChS) has implemented the Medical Surveillance Program (MSP) for workers, including the groups exposed to both high and extreme altitudes, to optimize their management, treatment, and prevention of complications.[8] It has 4 groups of activities: (1) income activities such as visit to company, validation report of exposed workers, and scheduling for worker evaluation; (2) evaluation activities such as sample taking, sample analysis, scheduling altered cases, and medical care; (3) results management such as issuance and delivery of reports; and (4) discharge activities, for instance, sample taking, sample analysis, and medical care (Figure 1).

The general aim of this study is to quantify the direct costs of operating the Medical Surveillance Protocol Program for Workers Exposed to High Altitude-induced Chronic Intermittent Hypoxia in Chile. The specific aims include quantifying the labor factor costs, consumables, and equipment usage and determining the average cost per worker participating in the program.

It is expected that the knowledge contributed will aid in: (1) evaluating, identifying, and quantifying the processes, resources, actions, and agents within the protocol established for this purpose, (2) projecting the expansion or improvement of the program owing to increased demand at the national level, and (3) making decisions regarding resource allocation for new implementations and improving and increasing the efficiency in general terms.

Methods

Setting

Iquique, Antofagasta, and Copiapó are 3 important cities located in northern Chile where companies conduct the principal copper mining operations. This geographic area concentrates practically half of all mine workers exposed to high working altitudes and therefore to CIH. It is estimated that the number of exposed workers reaches a total of 6014. In each of these cities, there is an agency of the AChS that endeavors, among other things, to implement the activities involved in the surveillance program. Each agency has health personnel such as doctors, nurses, paramedical staff, risk prevention engineers, and administrative staff. In addition, each facility has the equipment needed to fulfill the program protocols.

In these agencies, a survey was applied to collect data on site about consumption of resources, and on this basis the costs of each of the activities of the MSP were calculated through microcosting technic and a partial time-driven activity-based costing (TDABC) method.[9-12]

The program is divided into 3 major stages of design, operation, and control of the execution of surveillance. The object of costing of the present study corresponds to stage 2 of operation of the program.

Cost data collection

A direct cost survey was applied for each of the program activities, which was designed especially for this study and has the following parts:

1. Identification: This includes data such as the code of the activity, pre-estimated implementation time, the interviewer's name, and the respondent's name and position.
2. Labor factor costs: This includes the characterization of the professionals who participate in each activity, the number of minutes spent, and contracted working hours.
3. Input costs: This includes the identification of all the consumables involved in running the program, particularly the quantities used, units of measurement, and market prices expressed in consumption units.
4. Equipment use and furniture costs: This involves identifying all the equipment and furniture used to undertake the activities and years of service life.

A total of 123 on-site surveys were applied (41 activities to run the program in each of the 3 agencies). The data were provided by the head nurse of the program in each agency and were collected during a period of 3 months, from November 30, 2016, to January 30, 2017.

Remunerations, equipment market prices, and overhead cost data were provided at central level by the AChS. The market prices for consumables, however, were provided in each agency surveyed.

Model

An ad hoc method was designed for this case because this is the first time a cost study of the program was conducted. The decision was made to adapt the TDABC method to measure labor factor costs and equipment usage costs. To quantify input costs, the real amounts consumed and market prices were used. In relation to overhead costs, an estimated rate was applied to the direct costs (labor factor, consumables, and equipment usage costs). Figure 2 summarizes the costing model. The activities involved in operating the program were the main costing goal.

Step 1: determination of cost object and protocol of activities
This study focuses on the operating costs of the MSP that includes the following activity categories: (1) program introduction activities for workers; (2) periodic assessment; (3) results management; and (4) departure of the worker. Just to name a few, introduction activities include validation of the list of workers exposed, visits to the company where they work, and scheduling. Periodic assessment activities include issuing informed consent, taking samples, and analysis. Results management includes report issuance and submission, and finally, worker departure activities correspond to their optional assessment when leaving the program through withdrawal or transfer to another job.

Step 2: input of surveys into computer system
The direct cost surveys described previously in the data collection procedure were received centrally and entered into a database system run on Microsoft Access 2013 (Microsoft Corp, Redmond, WA).

Step 3: data review and validation
All the surveys were reviewed and the entered data were validated, verifying their consistency both in qualitative and quantitative terms.

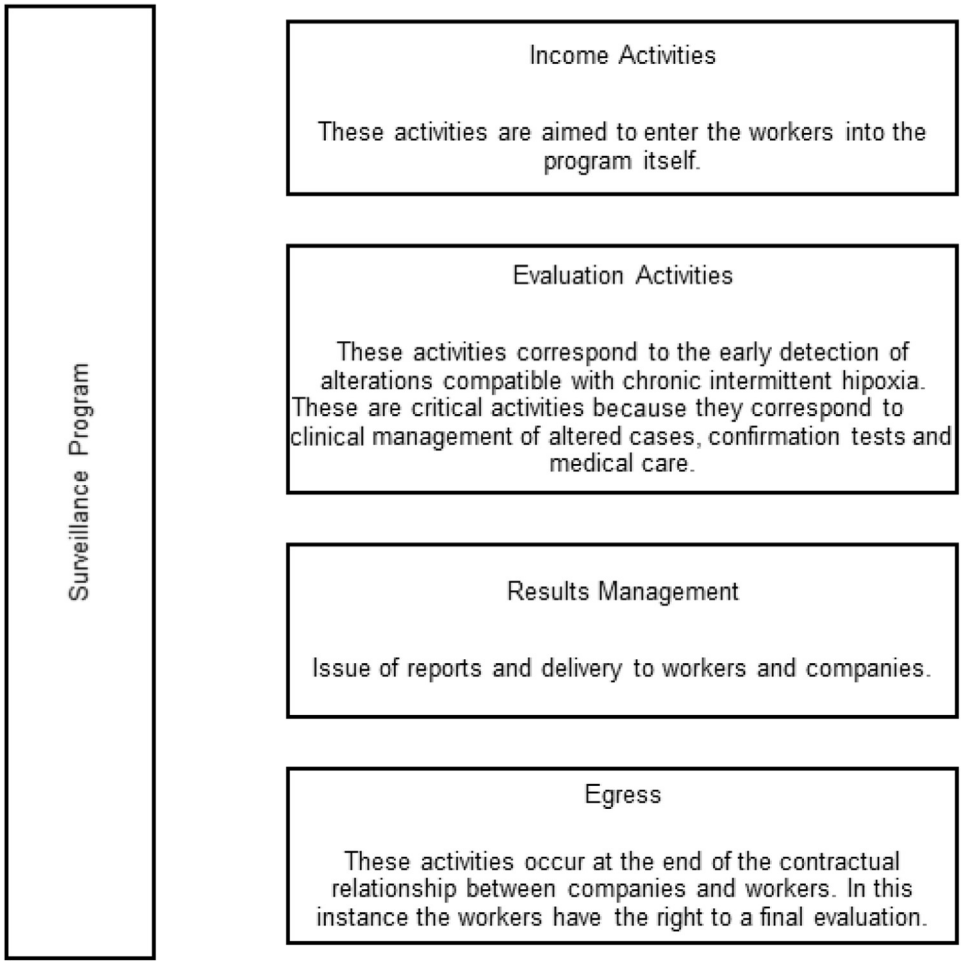

Fig. 1 – Simplified diagraph of medical surveillance.

Step 4: determination of activity costs

Labor factor costs. To allocate a cost for each activity in terms of the work factor, it is necessary to calculate a cost per minute for every professional involved in the program. Therefore, from the monthly gross salaries in Table 1, the labor factor cost per minute was determined according to the following formula:

$$CPMinute_{LF} = \frac{Annual\ Gross\ Salary}{\left(\frac{D_{year} - D_H - D_V - D_A}{7}\right) \times (J_{week} \times 60 - \lambda)}$$

Where:

D_{year} = Total calendar days in the year
D_H = Statutory holidays in the year
D_V = Legal vacation days
D_A = Administrative leave days
J_{week} Work week in hours (44)
60 = Minutes per hour
λ = Nonproductive weekly minutes

The numerator in the formula above is simply the annual gross salary. The denominator is based on 365 annual days, 16 real statutory holidays according to the 2016 calendar, 15 vacation days, and 6 administrative days. Contracted working hours were mainly 45 or 44 hours, and some were 33 and 22 hours. It was agreed to adjust the number of working hours, considering times allocated for breaks, bathroom breaks, and any other time not specifically allocated to the direct production of the program. Thus, for the denominator of the formula, the number of annual minutes considered for a 22-hour work week was 57 166 and for a 45-hour work week 121 829 minutes. The labor factor costs per minute ranged between a minimum of $0.06 (nurse technician 44-hour work week) and a maximum of $0.48 (physician 33-hour work week).

Once the previous calculations were complete, the labor factor cost per activity is:

$$Cost\ LF\ per\ Activity = \sum_{i=1}^{n} Minute\_Act_i \times CPMinute\_LF_i$$

where $Minute\_Act_i$ is the number of minutes of professional participation i in the activity i and $CPMinute\_LF_i$, is the labor factor cost per minute of professional i. The activity may require from 1 to n professionals.

Input costs. Table 2 details the types of consumables and materials normally used in the program. In this case, of primary importance was the verification of the amounts of consumption each time the activity was implemented and that the prices were expressed in the same consumption unit. The input cost for each activity is simply:

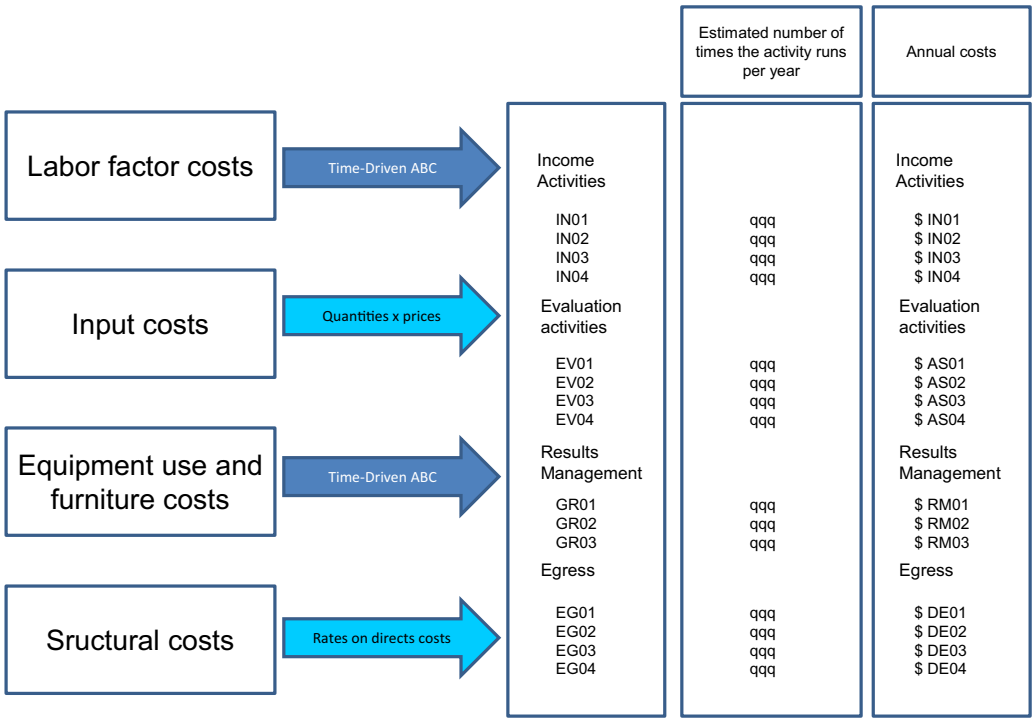

Fig. 2 – Simplified diagram of costing model. ABC, activity-based costing.

$$Cost\ Consumables\ per\ Activity = \sum_{i=1}^{n} Q_i \times P_i$$

where Q_i is the amount of consumable i consumed by the activity and P_i is the price of consumable i expressed in the consumption unit. An activity consumes from 1 to n types of consumables.

Table 1 – Professionals in the chronic intermittent hypoxia surveillance program, average monthly salaries by agency (in $ as of April 2017).

Agency	Worker or professional	Average monthly gross salary	Hours
Iquique	Nurse	$1677.00	44
	Nurse technician	$554.48	44
	Supervising physician	$2206.43	22
	Risk prevention expert	$2053.08	22
	Driver	$644.40	22
Antofagasta	Nurse	$1873.25	45
	Nurse technician	$689.36	45
	Supervising physician	$3527.64	33
	Risk prevention engineer	$2463.70	45
Copiapó	Nurse	$1873.25	45
	Nurse technician	$689.36	45
	Central team nurse	$1873.25	45
	Central team physician	$4810.41	45
	Risk prevention engineer	$1798.32	45
	Occupational health nurse	$1873.25	45

Equipment use costs. Table 3 contains the types of equipment, furniture, and durables used in the MSP and their replacement prices and service life expressed in years.

The cost per equipment usage in this study is based on the equivalent uniform annual cost (EUAC) of the goods. This is based on the economic value of an asset and represents the current value of the estimated future annual benefits that it will be able to generate. In addition, the underlying assumptions in this study were: (1) constant benefits of each piece of equipment per year, (2) very low residual value of the assets, (3) the equipment does not produce extra annual cash flows, and (4) its operating cost per year is low.

Three parameters are required for the calculation: (1) rate of opportunity cost of capital, which in this case is 3%, based on the Ministry of Health's Methodological Guide for Economic Assessment of Health Interventions in Chile[13]; (2) years of service life of the goods, and (3) the market price or replacement price of the different assets used. Thus, the EUAC is given by:

$$EUAC = VP \times \frac{(1+i)^n \times i}{(1+i)^n - 1}$$

where:

VP = Market or replacement price
EUAC = Equivalent uniform annual cost
i = Rate of opportunity cost of capital
n = Years of service life

This was calculated in MS Excel with the function: = -payment(i%; nper; va), where "i%" is the discount rate of 3%; "nper" is the years of service life and "va" is the replacement or market value of the assets. The function is preceded by the minus sign, so that it gives a positive result, because financially the concept payment is a negative sign.

Table 2 – Types of consumables for the chronic intermittent hypoxia surveillance program (in $ as of April 2017).

Code	Consumables	Quantity	Consumption unit	Price per consumption unit
4	Cotton	2	g	$0.007
8	Legal size white envelope	1	Unit	$0.153
9	Rechargeable toner	1-5	Sheets	$0.015
10	8.5 x 11 paper	1-6	Sheets	$0.007
11	Liquid soap	0.02	Canister	$3.851
14	Monarch envelope	1	Envelope	$0.153
17	Alcohol	10	mL	$0.007
20	Minutes book to sign for deliveries	1	Sheet	$0.081
22	Paper towel	2	Sheets	$0.004

Later, this annual usage cost was prorated to the different activities linked to the different pieces of equipment in proportion to the number of annual labor factor for each of them under the assumption that most of the work performed by the professionals in each activity involves the use of a computer and other furniture and equipment. The annual work commitment corresponds to the minutes in each activity multiplied by the number of times each activity is undertaken in the year.

A cost per minute of activity was calculated by dividing the EUAC by the sum of the annual labor factor minutes involved in all those activities that demanded the use of each piece of equipment.

The cost per use of a certain piece of equipment in the activities that require it is calculated on the basis of the following formula:

$$Cost\ per\ use\ equipment\ A_j = \frac{-payment(3\%; nper; va)}{\sum_{i=1}^{n} MinutesAño_{A_i}} \times MinutesEjec_{A_j}$$

The equipment usage cost in activity j is the cost per minute of the good multiplied by the minutes of implementation of activity j. The goods are generally used in more than one activity; therefore, the EUAC that appears in the numerator of the formula is divided by the sum of the annual minutes of all the activities the asset uses.

The goods demanded by a greater number of activities in the 3 agencies surveyed were the computers, soap dispenser, ergonomic chairs, office desks, and multifunctional printers.

Table 3 – Prices of equipment in the chronic intermittent hypoxia surveillance program ($ as of April 2017).

Code	ID Detail	Equipment, furniture, and durables	Replacement price	Service life (years)
1	31	Stryker cot	$ 3416.81	7
1	27	Painted stainless steel metal stretcher	$457.07	10
1	19	Two-step footstool with slip-resistant rubber	$41.96	10
3	28	Lenovo Pentium Intel computer	$790.21	3
4	23	Bright sanitizing soap dispenser	$63.34	2
5	12	AChS upholstered ergonomic chair	$211.84	7
6	13	Standard wooden office desks	$245.77	7
10	14	Nissan Terrano vehicle	$20 980.38	6
11	29	Lexmark MX61 DHE multifunctional printer	$794.24	3
12	20	Littman stethoscope	$84.30	7
14	34	Parametrizer	$2583.83	5

Overhead costs. The indirect overhead costs are all those costs different from labor factor, consumables, and equipment usage and are absolutely necessary to performing the program operations because they provide the logistical and infrastructure support. Energy, drinking water, gas, maintenance services, sterilization services, laundry, managerial and administrative support, and so forth are recurring examples of costs in healthcare programs. (At the industrial and commercial levels, the range of indirect overhead costs can extend to costs of engineering remunerations and production planning, equipment operations and programming, online real-time software costs, quality costs, material sourcing and transportation, corporate allocations for shared services, costs of processing customer orders, etc).

Given that many of these are costs shared between several healthcare programs or services, a distribution process is carried out (step-down method) that places them in cost centers and then on the level of individual programs or services and activities. In this study, the agencies surveyed do not perform this process; therefore, the decision was made to add a rate of 24% as an overhead cost for each of the activities, based on the literature, at both the national[14,15] and international[16-33] levels, which was then applied to the direct cost of the activities of the MSP.

Step 5: Delivery of results

All the processes for calculating costs per activity were done in Excel (Microsoft Corp, Redmond, WA) to take advantage of the flexibility and ease for reporting the relevant figures. The calculations of direct costs (work, consumables, and equipment) and overhead costs were recorded as a whole for all the activities and agencies on the respective spreadsheets in an Excel workbook. From these, using the functions in this program, the corresponding costs were produced per activity, costs per groups of activities, and annual costs of both the individual activities and groups of activities. Finally, the overall cost of the program for the 3 agencies and the average level per worker was given.

Results

The costs of each of the 41 individually considered activities are presented in Appendix Table 1 (in Supplemental Materials found at https://doi.org/10.1016/j.vhri.2019.01.011), disaggregated by items. These figures form the basis to obtain the other results of annual operating costs for each group of program activities (introduction, assessment, results management, and departure

Table 4 – Annual costs of the chronic intermittent hypoxia program: cost items in each group of activities ($ as of April 2017).

Group of activities	Cost items	Annual overall cost	%
Introduction activities	Labor factor	$19 131.49	55.31%
	Consumables	$112.97	0.33%
	Equipment usage	$8651.95	25.01%
	Total direct costs	$27 896.41	
	Overhead costs	$6695.14	19.35%
	Total activity cost	$34 591.55	100.00%
Assessment activities	Labor factor	$57 199.73	64.13%
	Consumables	$12 878.88	14.44%
	Equipment usage	$1850.42	2.07%
	Total direct costs	$71 929.03	
	Overhead costs	$17 263.10	19.35%
	Total activity cost	$89 192.13	100.00%
Results management	Labor factor	$219.02	68.57%
	Consumables	$28.58	8.95%
	Equipment usage	$9.98	3.12%
	Total direct costs	$257.58	
	Overhead costs	$61.82	19.36%
	Total activity cost	$319.40	100.00%
Departure activities	Labor factor	$1018.26	31.86%
	Consumables	$340.81	10.66%
	Equipment usage	$1218.74	38.13%
	Total direct costs	$2577.81	
	Overhead costs	$618.68	19.35%
	Total activity cost	$3196.49	100.00%
Total activities	Labor factor	$77 568.50	60.93%
	Consumables	$13 361.24	10.50%
	Equipment usage	$11 731.09	9.22%
	Total direct costs	$102 660.83	
	Overhead costs	$24 638.74	19.35%
	Total activity cost	$127 299.57	100.00%

activities) and the overall operating cost of the Program in each of the activities and for each worker. The annual cost projection was carried out through the estimation and quantification of the annual frequency that each activity presents. Table 4 shows the annual costs of the program in each category of activities, disaggregated by item. The figures correspond to the sum of the costs of the 3 agencies studied.

On average the cost of consumables represents 10.50% of the total cost, whereas the equipment usage is equivalent to 9.22% of the total costs. From this point of view, the direct costs are on average 80.65% of the total costs.

Table 5 – Annual operating costs of the chronic intermittent hypoxia Surveillance Program, in each group of activities ($ as of April 2017).

Code group of activities	Group of activities	Overall annual operating cost	%
IN	Introduction activities	$34 591.55	27.17
AS	Assessment activities	$89 192.13	60.06
RM	Results management	$319.40	0.25
DA	Departure activities	$3196.50	2.51
	Total	$127 299.58	100.00

The overall cost of the program stands at $127 299.57 per year, with an average cost per worker in the order of $21.17 considering a total exposed population of 6014 workers. In addition, the specific objectives were met, including quantifying the most important resources involved: labor factor, in the overall amount of $77 568.50 ($12.90 per worker), consumables ($13 361.24), and equipment usage ($11 731.09) (Table 5).

The design of the program operation in groups of activities of income, assessment, results management, and departure activities also made it possible to disaggregate the total costs into more significant activities, which are generally the assessment activities in the order of $89 192.13 (Appendix Table 1) and which represent 70.06% of the total operating costs.

Discussion

This is the first study into the operating costs of a surveillance program for workers exposed to high altitude–induced CIH in Chile. The literature review performed in this case revealed that there are no studies into the operating costs of a program of this nature in other places. Therefore, there are no references with which to compare figures.

It is important to note that the division of the program into activities is fundamental to measuring real costs because it is possible to identify the diversity in the consumption of resources and measure more accurately the costs in relation to different groups of activities involved in the program.

The information regarding the consumption of resources was collected in the field in the 3 geographic areas where the greatest concentration of copper mine workers in Chile are active; therefore, the data are quite representative. The number of workers in each agency surveyed is as follows: Iquique (3.146), Antofagasta (1.912), and Copiapó (1.692). The 3 agencies add up to 6.750, which is approximately equivalent to 46% of all workers in copper mining in Chile.

The time measurement expressed in labor factor minutes for each of the 41 activities included in operating the program made possible a precise allocation of the costs for medical personnel and nurses, among others, for each of the activities. It also enabled the allocation of equipment usage costs. The direct cost surveys revealed the real consumption amounts and costs of consumables for each activity.

As noted in Table 5, the participation costs of medical personnel in the different groups of activities are the most significant, averaging 60.93%. The greater participation in the assessment and results management activities is explained by the greater time used by medical personnel in performing and interpreting examinations.

The study presented the following limitations:

1. Discrepancies in the times reported for some of the activities in the different agencies, despite the fact that this information was provided by professionals with greater knowledge in the operation of the program.
2. Rate of overhead costs estimated on the basis of the literature because the organization that administers the program does not departmentalize these costs at program level.
3. The fact of being a partial evaluation of cost description only.
4. As a next stage of this study, the authors propose to investigate the gains in health and quality of life as a result of the operation of the surveillance program. In other words, it would be interesting to know how an intervention of this nature helps to increase productivity, reduce the rates of work absenteeism, and improve the organizational climate.

Conclusion

This study has made it possible to fulfill the general aim of determining and assessing the operating costs of the MSP for workers exposed to high altitude–induced CIH. The partial adaptation of the TDABC method in combination with the microcosting method provides a satisfactory solution to determine the total costs of operating a healthcare program of this kind, which includes multiple categorized activities and specific costs for labor factor, consumables, and equipment usage.

The results are consistent with findings from similar studies related to health programs in the sense that the labor factor has a significant participation within the total resources involved. Programs of this type also require high-cost equipment.

The present study has shown, for the first time in Chile, the dimensioning in monetary terms the cost it represents for an organization the operation of a surveillance program associated with a significant risk, which affects workers in an important sector of the national economy.

This program contributes to the prevention of health problems that potentially harm workers whose work at high altitude involves a significant risk to their job performance, and by doing so, avoids higher costs associated with treatments and follow-ups of chronic intermittent hypoxia.

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Supplemental Material

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.vhri.2019.01.011).

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