Occupational accidents in underground mining and effectiveness of control measures: Analysis in a gold mine in Colombia

Accidentes laborales en la minería subterránea y eficacia de las medidas de control:análisis en una mina de oro en colombia

Acidentes de trabalho em minas subterrâneas e eficácia das medidas de controlo: Análise numa mina de ouro na Colômbia

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Abstract— Underground mining is classified as a high-risk activity, which causes about 8% of fatal occupational accidents worldwide. Therefore, the effectiveness of the control measures established within the investigations of accidents occurring in an underground gold mine was evaluated by comparing two time periods (second half of 2018 and first half of 2019); in addition, the sustainability in a time of these control measures established in the first observation period was evaluated. To this end, an ambispective quantitative longitudinal study of an observational nature was carried out, based on the information collected using the Single Form for Reporting an Accident at Work and the Format for Investigating Incidents and Accidents at Work. During the periods analyzed, 181 events were reported, 55.8% occurred in the tunnel, 40% affected the upper extremities and 40.9% were caused by blow or contusion. After 6 months of implementing control measures, which were mainly training, the accident rate could be decreased by 3.8 accidents per 1,000 workers with a monthly downward trend. In conclusion, the permanence of the control measures contributed to the reduction of the accident rate both in the new events and in their recidivism.

Keywords—Accident at work, Intervention measures, Underground mining, Risks.

Resumen— La minería subterránea es catalogada como una actividad de alto riesgo, que causa mundialmente cerca del 8% de los accidentes laborales mortales. Por tanto, se evaluó la efectividad de las medidas de control establecidas dentro de las investigaciones de los accidentes ocurridos en una mina aurífera subterránea mediante la comparación de dos periodos de tiempo (segundo semestre 2018 y primer semestre de 2019), además se evaluó la sostenibilidad en el tiempo de éstas medidas de control establecidas en el primer periodo de observación. Para ello, se llevó a cabo un estudio cuantitativo longitudinal ambispectivo, de carácter observacional; a partir de la información recogida mediante los formatos Formulario Único de Reporte de Accidente de Trabajo y Formato de investigación de incidentes y accidentes de trabajo. Durante los periodos analizados, se reportaron 181 eventos, 55,8% ocurrieron en el túnel, 40% afectaron las extremidades superiores y 40,9% se ocasionaron por golpe o contusión. Luego de 6 meses de implementación de medidas de control, las cuales principalmente fueron capacitaciones, la tasa de accidentalidad disminuyó en 3,8 accidentes por cada mil trabajadores con una tendencia mensual a la baja. Como conclusiones, la permanencia de las medidas de control puede contribuir en la reducción de la accidentalidad tanto de nuevos eventos como en su reincidencia.

Palabras clave— Accidente de trabajo, Medidas de intervención, Minería Subterránea, Riesgos.

Resumo— A exploração mineira subterrânea é classificada como uma actividade de alto risco, que causa globalmente cerca de 8% dos acidentes de trabalho fatais. Por conseguinte, a eficácia das medidas de controlo estabelecidas no âmbito das investigações de acidentes ocorridos numa mina de ouro subterrânea foi avaliada comparando dois períodos de tempo (segunda metade de 2018 e primeira metade de

2019), e a sustentabilidade ao longo do tempo destas medidas de controlo estabelecidas no primeiro período de observação foi também avaliada. Para este efeito, foi realizado um estudo quantitativo longitudinal ambispectivo, de carácter observacional, baseado na informação recolhida através do Formulário Único de Relatório de Acidentes de Trabalho e do Formulário de Investigação de Acidentes de Trabalho e Incidentes de Trabalho. Durante os períodos analisados, foram notificados 181 eventos, 55,8% ocorreram no túnel, 40% afectaram os membros superiores e 40,9% foram causados por golpes ou contusões. Após 6 meses de implementação de medidas de controlo, que consistiram principalmente em formação, a taxa de acidentes diminuiu 3,8 acidentes por mil trabalhadores, com uma tendência mensal para a diminuição. Como conclusões, a permanência das medidas de controlo pode contribuir para a redução da taxa de acidentes, tanto em novos eventos como na sua recorrência.

Palavras-chave— Acidente de trabalho, Medidas de intervenção, Mineração subterrânea, Riscos.

I. INTRODUCTION

Colombia is classified as a highly metallogenic territory, so the mining sector is dedicated to the exploration and exploitation of minerals such as gold, copper, and coal for the use and obtaining of resources with economic potential for the benefit of the nation and its citizens (Ministry of Mines and Energy & Universidad Pedagógica y Tecnológica de Colombia, 2018). However, the labor, environmental and land conditions in which the mines are geographically located expose their workers to different risk factors for their health and life (Castellanos et al, 2016; Gonzalez M, Molina V, & Patarroyo G, 2019); on this, the International Labor Organization mentions that mining, although it represents 1% of the world labor force, contributes 8% of fatal accidents at work (International Labor Organization, 2015), likewise in 2018, Colombia reported 112 deaths, with a rate of 2 deaths per million worker hours (National Mining Agency, 2019).

Even though the Colombian Government has been generating mandatory regulations on occupational safety and health, in terms of legal requirements, minimum standards, sanctions, and fines; the figures for occupational accidents and mortality have not decreased significantly in recent years (Agencia Nacional de Minería, 2019).

However, to comply with these legal requirements, organizations, regardless of the economic sector to which they belong, must carry out investigations of work incidents and accidents as established in Resolution 1401 of 2007 and Decree 1072 of 2015 in its article 2.2.4.6.32. (Ministry of Social Protection, 2007; Ministry of Labor, 2015) These investigations led to the determination of intervention measures, whether preventive and/or corrective and/or of improvement, which should contribute to minimizing the probability of recurrence of these events, and consequently to the continuous improvement of the Occupational Health and Safety Management System, according to Law 1562 of 2012 (Congress of Colombia, 2002).

With the present investigation, we aimed to characterize work accidents and evaluate the effect and sustainability of control measures in gold miners in Colombia between July 2018 and June 2019.

Based on the foregoing considerations, the analysis made it possible to recognize deviations, whether from unsafe conditions that are the responsibility of the employer or unsafe acts that are the responsibility of the workers, so that the company could determine where to point its efforts, with the main purpose of avoiding injuries to each of the workers.

II. METODOLOGY

A) Study Variables

The dependent variables analyzed were accidents and recidivism reported through the Single Form for Reporting an Accident at Work (FURAT). As an independent variable, the proposed control measures for accidents reported in the Format for Investigation of Incidents and Accidents at Work (FIIAT) were taken into account. In addition, to evaluate the sustainability of the control measures over time, an observation list was designed that included the control measures defined in the investigations of accidents at work, which was evaluated by an external expert with experience in underground mining and safety and health.

B) Methodological Design

Ambispective longitudinal observational study of case report about accidents in mining, because the information corresponding to 2018 was collected retrospectively from the aforementioned forms, while information on recidivism was taken prospectively in 2019.

C) Population and Sample

The events included in the sample were all those derived from the mining operation: from operating personnel to management personnel, adults, men, and women, who work directly with the company under study.

Of the total events that occurred in the periods (second semester of 2018 and first semester of 2019), classified as occupational accidents, do not include those generated by biological hazards, public order, or those cases where the information was incomplete or presented any anomaly this by the provisions of Law 1562 of 2012 article 3rd.

Table 1. Sociodemographic and occupational characteristics of gold mining workers injured by semester, 2018-2019.

Sociodemo graphic and occupational characteristics	Semester 2-2018 n=105	Semester 1-2019 n=76	Total n= 181	p-value
Average age (SD)	30.8 (7.9)	32.7(12,2)	31.6 (9.9)	0.09†
Sex, n (%)				
Male	98 (93.3)	72 (94.7)	170 (93.9)	0.69¥
Female	7 (6.7)	4 (5.2)	11 (6.1)	
Educational level, n (%)				
Undefined schooling	27 (25.7)	15 (19.7)	42 (23.2)	0.51¥
Primary	5 (4,8)	2 (2.6)	7 (3.9)	
Secondary	42 (40)	26 (34.2)	68 (37.5)	
Technician or technologist	24 (22.9)	24 (31.5)	48 (26.5)	
Professional	5 (4,8)	5 (6,5)	10 (5.5)	
Postgraduate	2 (1.9)	2 (2.63)	4 (2.2)	
Title, n (%)				
Operating	97 (94.2)	63 (82.8)	160 (88.3)	0.015‡
Staff	8 (5.8)	13 (17.1)	21 (11.7)	
Experience in years, average (DS)	1.,3 (2)	1.9(2.2)	1.5 (2)	0.03†

†: Student's T-test, ¥: Fisher's exact test, ‡: Pearson's Chi2-test

D) Techniques and tools for data collection and analysis.

To collect the information, databases established under the custody of the company under study were used, for which permission for access to the

information was formally requested through written communication. Once this information was available, the data were supplemented based on FURAT and FIIAT, in which an Excel matrix was subsequently created with the data related to the study variables, excluding the data that identified the subjects, assigning them a consecutive number.

To evaluate the sustainability of the control measures over time, a checklist was drawn up and submitted to the judgment of occupational safety and health experts with experience in underground mining. This list was drawn up based on the analysis of investigations of occupational accidents and was applied inside the mine and on the surface.

E) Data analysis (statistical)

Univariate: measures of central tendency (mean) and dispersion (standard deviation), absolute frequencies and percentages; Bivariate: Chi-square and exact tests by Fisher, T by Student. STATA 13 analysis software.

III. RESULTS

There were 181 industrial accidents, of which 105 (58.0%) occurred in the second semester of 2018 with a rate of 16.5 and 76 (41.9%) in the first semester of 2019 with a rate of 12.7.

Most of these events were suffered by men (93.9%), operating personnel (88.3%), and workers with a secondary schooling degree, and technicians or technologists (64%) (Table 1).

A significant difference was found in accident rate according to work experience (p=0.03), those who were injured in the second semester of 2018 have less work experience compared to those who suffered accidents in the first semester of the following year. There was also an increase of 11.3% in the accident rate among staff and, on the other hand, the accident rate fell by 11.4% among operational staff. (p=0.015) (Table 1).

Concerning the place of occurrence, the greatest number of events took place in the tunnel (55.8%); on the other hand, there was a significant reduction (21.8%) of accidents in production areas (p=0.01) See Table 2.

Table 2. Characteristics of the work accident of gold mining workers who had an accident during the 2018-2019 semesters.

Characteristics related to the accident at work	Semester 2-2018 n=105	Semester 1-2019 n=76	Total n=181	P-value
Place of accident, n (%)				
Tunnel	52(49.5)	49(64.5)	101 (55.8)	0.01¥
Production areas	38(36,2)	11 (14.4)	49 (27.1)	
Warehouses or depots	4 (3.8)	8 (10.5)	12 (6.6)	
Parking or circulation areas	2 (1.9)	0 (0.0)	2 (1.1)	
Corridors	1(0.95)	0 (0.0)	1 (0.6)	
Other common areas	8 (7.61)	8 (10.5)	16 (8.8)	
Affected part (%)				
Upper limbs	42(40.0)	29(38.1)	71 (39.2)	0.93¥
Lower limbs	26(24.7)	19(25.0)	45 (24.8)	
Head, neck and eyes	16(15.2)	13(17.1)	29 (16.0)	
Trunk/thorax	13(12.4)	9(11.8)	22 (12.2)	

General or other injuries	6(5.7)	6(7.9)	12 (6.6)	
General or other injuries	2(1.9)	0(0.0)	2 (1.1)	
Type of injury n (%)				
Hitting contusion or crushing	47(44.7)	27(35.5)	74 (40.9)	0.38¥
Sprain, sprain, muscle tear	28(26.6)	21(27.6)	49 (27.1)	
Wound	9(8.5)	8(10.5)	17 (9.1)	
Superficial trauma	2(1.9)	7(9.2)	9 (5,0)	
Electricity effect	1(0.9)	2(2.6)	3 (1,7)	
Multiple injuries	1(0.9)	1(1.31)	2 (1,1)	
Asphyxiation	1(0.9)	0(0.0)	1 (0.6)	
Burn	1(0,9)	0(0)	1 (0,6)	
Other	15(14,2)	10(13,1)	25 (13,8)	
Accident mechanism n (%)				
Stroke	22(20.9)	17(22.3)	39 (21.5)	0.82‡
On muscular effort	15(14.2)	11(14.4)	26 (14.4)	0.97‡
Falls to level	20(19.0)	5(6.5)	25 (13.8)	0.01‡
Rock fall	12(11.4)	10(13.1)	22 (12.2)	0.73‡
Trapping	5(4.7)	0(0.0)	5 (2.8)	0.06¥
Fall of objects	2(1.9)	3(3.9)	5 (2.8)	0.35¥
Exposure to or contact with chemicals	3(2.8)	2(2.6)	5 (2.8)	0.65¥
Exposure to or contact with electricity	1(0.9)	2(2.6)	3 (1.7)	0.38¥
Other	25(23.8)	26(34.2)	51 (28.2)	0.13‡
Accident Agent n (%)				
Working environment	23(21,9)	29(38,2)	52 (28,7)	<0.001¥
Machines and/ or equipment	22(20,9)	13(17,1)	35 (19,3)	
Tools elements or utensils	14(13,3)	16(21,0)	30 (16,6)	
Materials or substances	30(28,5)	5(6,6)	35 (19,3)	
Other agents not classified	16(15,2)	13(17,1)	29 (16,1)	
¥: Fisher's Exact Test, ‡: Pearson's Chi2 Test				

About the affected body part, events occurred mostly in the upper limbs (39.23%); while the highest frequency by type of injury was blown, contusion, or crushing with 74 events (40.9%). A significant reduction (13.5%) was found in accidents related to level falls (p=0.01). Additionally, differences were observed in the accident agent (p<0.001) with reductions in those caused by machines, equipment, materials, or substances (Table 2).

On the other hand, during the observation period, there were two serious accidents (1.1%), one in the first semester of 2019 (fracture of the major tuberosity of the right humerus, right shoulder muscle strain) and one in the second semester of 2018 (fracture of the left humerus).

Table 3. Accidentality analysis of gold mining workers by six-month period, 2018-2019.

Analysis of accident rate (%)	Semester 2-2018 n=105	Semester 1-2019 n=76	Total n= 181	p-value
Severity Mild Serious	104(99.0) 1(0.9)	75(98,6) 1(1.3)	179(98.9) 2 (1.1)	0.066¥
Deviation Unsafe act Unsafe condition	53(50,5) 52 (51.3)	45(59.2) 31(45.8)	98 (54.1) 83 (45.8)	0.016‡
†: Student's T-test, ¥: Fisher's exact test, ‡: Pearson's Chi2-test				

Table 4. Action plans implemented in gold mining workers injured by semester, Buriticá, 2018-2019.

Action Plans n (%)	Semester 2-2018 n=105	Semester 1-2019 n=76	Total n= 181	p-value
Controls Administrative control Engineering Control	103(98.09) 2(1.90)	69(90.7) 7(9.2)	172(95.0) 9(4.0)	0.030¥
Sub-planning action plans n (%) Administrative control Training Define standards Signal Install spare part	40(38.8) 57(55.3) 6(5.82) 0(0.0)	58(84.0) 10(14.4) 0(0.0) 1(1.44)	98(56.9) 67(38.9) 6(3.4) 1(0.5)	<0.001¥
Engineering Control Adapt Area Modify equipment	0(0.0) 2(100)	6(85.71) 1(14.3)	6(6.66) 3(3.33)	0.08¥

Implementation of Action Plan n (%) YES NO	96(91.4) 9(8.6)	55(72.3) 21(27.6)	151(83.4) 30(16.5)	0.001‡
Opportunity in research YES NO	92(87.6) 13(12.3)	48(86.1) 28(36.8)	140(77.3) 41(22.6)	<0.001‡

†: Student's T-test, ¥: Fisher's exact test, ‡: Pearson's Chi2-test

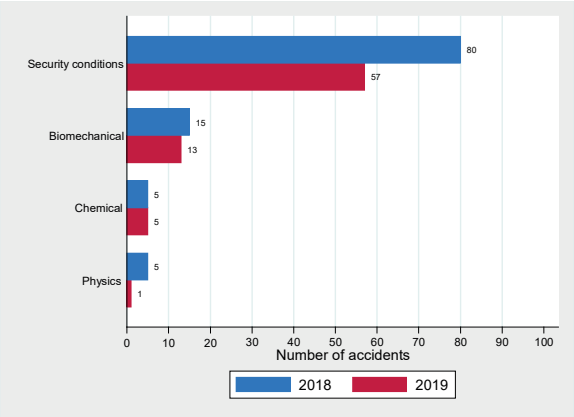

Fig. 1. Analysis of accidentality due to danger in gold mining workers, accidents per semester. Buriticá 2018-2019

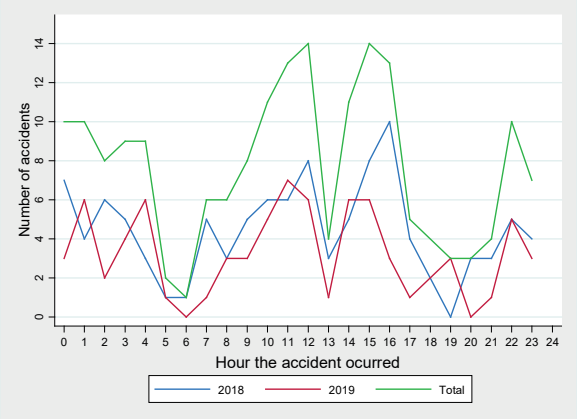

Fig. 2. shows accident peaks between 10:00 and 12:00 hours and between 14:00 and 17:00 hours and the opposite shift between 22:00 and 3:00 hours, with similar behavior observed between 2018 and 2019.

Similarly, there was a higher accident rate on Saturdays (19.3%), followed by Mondays (18.7%), while Thursday was the day with the lowest number of events (8.8%). (Figure 3)

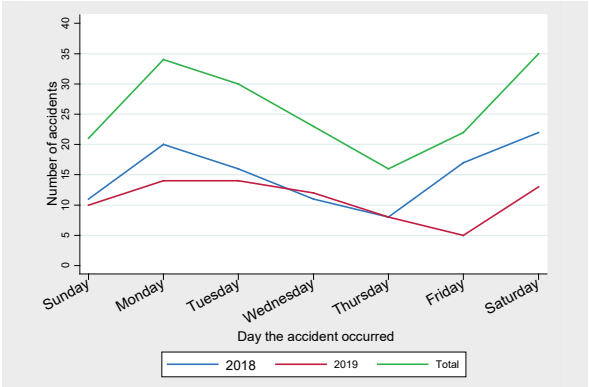

Fig. 3. Analysis of accidentality per day of occurrence in gold mining workers injured per semester, Buriticá, 2018-2019.

The control measures carried out in the second half of 2018 had a positive effect in the first half of 2019, which was reflected in the decrease in the average accident rate per thousand workers. It dropped from 16.5 (Dev. Est. 3.36) cases in 2018 to 12.7 (Dev. Est. 2.94) cases in 2019 (T-test, p=0.03), for a reduction in the monthly accident rate of 3.8 accidents per thousand workers.

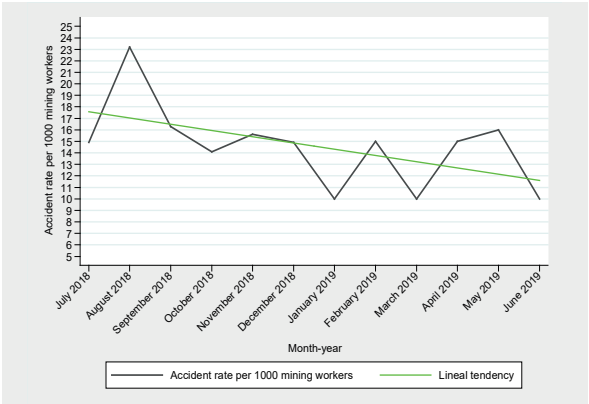

Fig. 4. Analysis of monthly accidentality of occurrence in gold mining workers accident by semester, Buriticá, 2018-2019. Monthly Accident Trend

About the behavior of the accident rate per month, it is observed that in the period under study, the months with the fewest events correspond to January, March, and the months with the highest accident rate to August and May.

IV. DISCUSSION

This study found that after six months of implementation of control measures, which were mainly training, the accident rate decreased by 3.8 accidents per thousand workers with a monthly downward trend, mainly for operating personnel, this is consistent with what was reported by Watkins et al (Watkins, Dabestani, Nugent, & Levin, 2017); who states that training programs for personnel in the execution of tasks, is superior to engineering and ergonomics programs, in terms of effectiveness and cost required by it.

García Mainar et al (García Mainar & Montuenga Gómez, 2009), mention that by increasing work experience, the probability of accidents is reduced, which implies sensitizing newly hired workers. In the present study, a trend was observed in the reduction of accidents among workers with less experience, probably related to the training programs developed in 2018.

As for the affected body part, a reduction in accidents in upper and lower limbs was found; it should be noted that within the measures implemented in 2018, a campaign of hand protection and mechanical risk management was carried out; this finding was similar to that of Cruz Rodríguez (Cruz Rodríguez, 2018) who found a reduction in the number of accidents affecting the legs of mining workers in Perú, associated with government control and implementation of control measures by employers.

On the other hand, a representative decrease was identified according to the type of injury, specifically due to blows, contusion, or crushing; this decrease is possibly associated with prevention campaigns carried out during 2018; similarly, in the construction sector, Bedoya-Marrugo et al, identified this same type of injury as having a greater incidence due to the handling of cargo, tools, equipment, and substances.

In turn, the mechanism that had a statistically significant decrease between the two periods compared was the falls to the same level, this possibly related to the control measure in the maintenance of the streets. In this sense, T. Rivas (Rivas et al., 2011), mention a decrease in the occurrence of occupational accidents by this mechanism and points out that it is due to the efforts of companies in the implementation of preventive measures.

The study identified accident peaks between 10:00 and 12:00 and between 14:00 and 17:00 day shift, which coincides with the period before and after food consumption and the end of shift; consistent with what Sanmiquel et al. (Sanmiquel, Bascompta, Rossell, Anticoi, & Guash, 2018), identified in their study, that the accident originated in the

early hours of the day and after the lunch break. This is also consistent with the findings of Stemn E, who found that around 75% of injuries occurred during the morning shift and underground fatalities far exceed surface fatalities, and 10:00–12 and 13:00–14:00 were the peak injury periods (Stemn, E., 2019).

It was identified that the days where most accidents occurred were, in the first place, Saturday, possibly related to: the arrival of the weekend, enjoy rest, or participate in local festivals. López et all (López Arquillos, Rubio Romero, & Gibb, 2012), refer to the increase in the occurrence of accidents on Mondays, as a result of the weekend's extra-occupational activities but which are reported as occupational to receive the benefits of the health and occupational risk systems.

V. CONCLUSION

The characterization of the work accident in the organization allowed to identify the schedules, days, and months in which the events are presented. This identification facilitates the analysis of the real causes that originate from them.

The accident profile for the gold mining sector is given by injuries: sprains-sprains and contusions-crushes, mainly in the upper limbs, of mechanical types and occurring mostly in the tunnel.

The evaluation of the permanence of the implementation of the control measures had a positive influence on the reduction of accident indicators in the following period to the implementation of the measures, presenting a reduction of 29 events and a rate of 3.8 accidents per thousand workers per month.

The control that was most established in investigations of accidents at work was administrative control - training, especially focused on the execution of the activities of the workplace; control that yields results that contribute to the reduction of accident indicators, and that has a lower cost than other controls such as engineering.

A) Recommendations and limitations

It is recommended that investigations of occupational accidents be carried out within the legally defined time frame in Colombia. This guarantees that the information provided by those involved does not change and that, promptly, the necessary controls are determined to correct the possible deviations presented and prevent other workers from being injured in similar situations.

Organizations should socialize the results of investigations into accidents at work and the proposed control measures with all company personnel, extending the measures in all areas and not just where the event occurred.

It is recommended to include within the health group of the company, a professional in Psychology with training

in health and safety at work, who implements the behavior-based safety program and a physiotherapist for the follow-up of injured workers and the implementation of the epidemiological surveillance program for risks of Biomechanical type.

Measures must be taken that really impact the root causes of accidents, especially those occurring in tunnels, since it is in this area where the greatest number of events occurred, defining better safety standards and giving priority to the integrity of workers before the operation.

The control measures verification tool that was defined presented a limitation in that it grouped the action plans in a general way and not for each event, which would have allowed more specific results to be identified for each type of plan.

The information provided, characterized, and taken from the Work Accident Investigation Formats (FIIAT) was not modified; however, it was evidenced in some cases that the causes identified were not the root cause, so the action plans defined did not prevent the recurrence of similar work accidents.

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