THE USE OF CHEMICAL AGENTS BY LAW ENFORCEMENT IN CONTROLLING CIVIL DISORDERS

Original Scientific Article

DOI: 10.5937/zurbezkrim2201033S	UDK 351.814.1:351.74/.76

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Abstract: This study seeks to determine the spatial and temporal concentration of chemical agents (specifically – orthochlorobenzylidenemalononitrile – corson & stought (CS)) used by law enforcement in controlling civil disorders, depending on meteorological conditions and the time of the day. This study was conducted using the Gaussian air pollutant dispersion model. Based on findings of this study, conclusions pertaining to distance (in meters) and duration (in seconds) of the use of chemical agents under favorable, average, and unfavorable meteorological conditions, as well as conditions determined by the time of the day, both in urban and rural areas were drawn. Based on these conclusions, recommendations were made for the management and tactics of the engagement of police units in situations where the use of chemical agents occurs. Additionally, recommendations for future research in this area have been identified.

Keywords: chemical agents, conditions, space, time, concentration, incapacitation

INTRODUCTION

In addition to legality, the use of chemical agents[2] by law enforcement in controlling civil disorders[3] also requires efficiency understood as the rela-

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2 Chemical agents are agents whose toxic effects cause the interruption of the persons' activities against whom they are used, without their consent. This effect is achieved by appropriate concentrations of chemical substances, which irritate the mucous membranes of the eyes, nose and trachea, the rest of the respiratory system, digestive tract and skin, which temporarily incapacitate the affected person. The first signs of poisoning are tingling and pain in the eyes, the production of tears, coughing, etc. At higher concentrations, there is temporary blindness, increased salivation, difficulty breathing, pain in the chest and skin. At even higher concentrations, nausea, vomiting or cramps occur. Unprotected persons exposed to the effects of these toxins almost immediately become incapacitated, and such a condition lasts longer than when exposed to its effects, which amounts to 10 to 20 minutes (Subošić, 2005: 50-51).

3 Civil riots and internal unrest, riots and tensions, are particularly characterized by acts of violence having unusual proportions, which are usually accompanied by a sense of impunity for the

tionship between effectiveness (maximizing the effects) and economy (as little as possible). However, it is necessary to take into account all the factors of the use of chemical agents, which include the opponent (in this model, the assumed average height of the face – eyes, nose and mouth of 1.7 m), their own strength (considered through the means of coercion used, in this case it is *ortho-Chlorobenzylidene malononitrile* known as *Corson & Stought* (CS)),[4] which is emitted from an activated M1 hand grenade manufactured by *Trayal Corporation*, https://trayal.rs/eksplozivi-i-pirotehnicka-sredstva/pirotehnicka-neubojna-sredstva/iritirajuca-sredstva / (18.11.2021.)), which forms a contaminant in the form of clouds after the emission of chemical matter (see technical characteristics of the M1 bomb in *Table 2*), space (open, in urban and rural areas),[5] and weather conditions (meteorological conditions and the time of the day, as determined in the table below the first subtitle of the paper). In this regard, there are some guidelines regarding the use of chemical agents by law enforcement to control civil riots. Most of the rules refer to the use of wind to transfer chemical matter to the opponent in order to contaminate and incapacitate them to undertake illegal activities. For example, wind speed and direction affect the application of chemical agents. Wind direction can be frontal, dorsal, lateral and oblique. In relation to wind direction, the place from which the chemical will be emitted is determined (for example, if the wind emanates from the police to the opponent, the line of chemical development is in front of the police cordon[6]). Additionally, according to these (modest) rules, wind speed affects the dimensions of the smoke wave. The length of the smoke wave is calculated by the following formula:

$$D \text{ (m)} = v \text{ (m/s)} \times 60 \text{ s} \qquad (1)$$

where:

- D (m) – length of the smoke wave in meters
- v (m/s) – wind speed in meters per second.

According to the same formula, if wind speed amounts to 5 m/s, the length of the smoke wave is 300 meters. At the same time, it is considered that it is not expedient to emit chemical matter at wind speeds equal to or greater than 10

participants who commit a number of misdemeanors and/or crimes (Stevanović, 2019: 35).

4 Tear gas (commonly referred to as CS gas) occupies a significant place among the weapons and equipment for counter-terrorism units, which is supported by the fact that 78% of such police units in the USA had them in their material formation in 1995 (Kraska & Gaines, 1998: 23).

5 Relief shapes affect the propagation of the smoke wave through uneven terrain, forests and buildings. Earth unevenness is followed by smoke wave in the direction of the wind by monitoring the configuration. Forests affect the movement of the smoke wave by retaining it, maintaining the concentration of the chemical substance, which means that the contamination lasts for a very long time. In settlements, the smoke wave moves the way it is channeled by facilities, such as buildings and streets, which includes the significant impact of parks, underground passages and so on (Lazarević, 2001: 32-34).

6 The cordon means police intervention machine.

m/s (Lazarević, 2001: 28-29). [7] In this regard, the following questions arise: 1) which concentrations of contaminants are achieved at certain distances, especially at which distances the incapacitating concentrations are created and how far they can travel (from – to in meters) and 2), how long it takes for them to be created and how long the incapacitating concentrations of contaminants last (from – to in seconds).[8] This paper seeks to determine the spatial and temporal concentration of chemical agents used by law enforcement in controlling civil disorders, depending on meteorological conditions and the time of the day. The knowledge gained is important for the management and tactics of the engagement of police units (security forces in general) to perform these tasks.

CHEMICAL AGENT *ORTHO-CHLOROBENZYLIDENE MALONONITRILE* (CORSON & STOUGHT – CS)

Chemical irritants were merged during the course of their development and, as a result, combined agents were created, which simultaneously achieved the effects of tear gas and sneeze gas.[9] CS is a typical representative. It was synthesized in 1928, and the English police were the first to use it to suppress demonstrations in Northern Ireland, while the British army has been using it since 1958 (Grupa autora, 1980: 211, 221; Bokonjić, 1985: 88). Although these chemicals constitute the essence of irritants, their use is impossible without devices and delivery methods. According to Ivan Lazarević: "Chemical agents for temporary incapacitation include: (1) chemical substances causing temporary incapacitation, (2) devices, and (3) delivery methods" (Lazarević, 2001: 3). Mass application of this product is a consequence of its persistence under conditions of humidity and other meteorological inconveniences. By using the chemical substance ***CS*** in the appropriate concentration, four types of effects can be predicted, as follows:

- *irritation threshold*: represents the minimum concentration (quantity per unit volume) of chemical substance in the air, which causes the appearance of signs of contamination,
- *tolerance limit*: represents the highest concentration of a chemical substance that can be tolerated in a contaminated person with pronounced signs of contamination,

7 The width of a smoke wave is determined depending on its length (which depends on the wind speed) and it can be determined with satisfactory accuracy by applying the 1/5 rule, which reads: "The width of a smoke wave is 1/5 long at the current wind speed" (Lazarević, 2001: 29).

8 The width and height of the contaminant, depending on the conditions of its emission, will not be discussed in this paper.

9 One of the oldest non-lethal weapons is the riot control/tear agent *Chloroacetophenone*, which was discovered in 1871 or 1874, which is also used in modern security practice (Vojvodić, 1981: 276). The use of this tear gas, better known as CN, was first recorded in 1912 in Paris during civil disorders. Due to its success, primarily because of surprise, it began to be used in the army as well (Lazarević, 1997: 51).

- *intolerable concentration*: represents the concentration of a chemical substance that causes effective *incapacitation* quickly (usually in one minute),
- *lethal concentration*: represents the concentration of a chemical substance that causes lethal consequences in a contaminated person within minutes (Lazarević, 2001: 8).

The defined chemical concentrations are shown in Table 1.

Table 1. Effects of the use of chemical agents in the appropriate concentration (Lazarević, 2001: 8)

Chemical agent	Irritation threshold (mg/m^3)	Tolerance limit (mg/m^3)	Intolerable concentration (mg/m^3)	Lethal concentration (mg/m^3)
CS	0,05-0,1	1-5	10-20	40000-75000

CHEMICAL GRENADES

Chemical grenades are usually cylindrical or ball-shaped. Depending on the mode of action, chemical grenades can be explosive grenades or thermo-generator grenades (in this case, such grenades are considered). Thermogenerator grenades are usually made of solid plastic or metal, and in addition to lighters, they also contain a pyrotechnic mixture with a chemical substance. Additionally, the chemical substance of the same grenades can be combined with the explosive substances of "shock" grenades, resulting in combined grenades for temporary incapacitation. Due to its own lighter, chemical grenades can be used in several ways, but in this case, we consider hand grenades which are activated using an overhand throw.

Table 2. Technical characteristics of a hand grenade (https://trayal.rs/eksplozivi-i-pirotehnicka-sredstva/pirotehnicka-neubojna-sredstva/iritirajuca-sredstva/ (18.11.2021.))

Chemical grenade	Grenade M1, CS
Description	RB M1 is a pyrotechnic device intended for the temporary incapacitation of unprotected people indoors and outdoors, the performance of complex military and police tasks in the fight against infiltrated terrorist-sabotage groups; it is used in the searches of premises and facilities, in encircling and blocking, ambush attacks, for the purpose of suppressing mass civil disobedience, resistance and rebellion, including all traditional forms of combat operations.

Chemical grenade		Grenade M1, CS
Device		RB-M1 belongs to the group of devices used to create a poisonous smoke wave. The body of the bomb is made of sheet steel, cylindrical in shape. By acting on the target, it creates a contaminated atmosphere, causing temporary incapacitation of unprotected people. Unprotected people experience severe irritation, a stinging sensation in the eyes and mucous membranes, severe tearing, blurred vision, coughing, breathing difficulties and suffocation, which significantly reduces the physical and mental activities of the people exposed.
Technical characteristics	Active charging	CS
	Active substance mass	70 g
	Pyrotechnic mixture mass	240 g
	Smoke emission time	30-40 s

WEATHER CONDITIONS (METEOROLOGICAL CONDITIONS AND THE TIME OF THE DAY) FOR THE USE OF CHEMICAL AGENTS BY LAW ENFORCEMENT IN CONTROLLING CIVIL DISORDERS

Weather conditions: 1) speed (m/s) and 2) wind character, 3) the vertical stability of air, 4) air temperature and cloudiness, 5) the time of the day, 6) humidity, 7) pressure, and 8) precipitation are key variables important for the efficient use of chemicals. For each time variable, three states of its manifestation are possible: favorable, average, and unfavorable conditions. In this regard, the following table is provided.

Table 3. Weather conditions for the use of chemical agents

ELEMENTS	FAVORABLE	AVERAGE	UNFAVORABLE
WIND SPEED (m/s)	2-5	6-8	Less than 2 and over 8
WIND CHARACTERISTICS	Constant speed and direction toward the opponent		Unstable, burst or in the direction of the police, that is, when there is no wind
VERTICAL STABILITY OF AIR	Inversion	Isotherm	Convection
AIR TEMPERATURE AND CLOUDINESS	Cold, cloudy (low clouds)	High clouds	Sunny, hot, very dry weather
THE TIME OF THE DAY	Early morning, late evening	Late morning and early afternoon	Around noon
HUMIDITY	High	Average	Low (dry)
PRESSURE	High	Normal	Low
PRECIPITATION	No precipitation	Immediately after	Precipitation in progress

METHODOLOGY

The concentration of air pollutants (pollutants, impurities) is calculated using mathematical models. Deterministic models are mostly used, which are divided into Lagrangian, Eulerian, and Gaussian models. The Gaussian model was used, because it is the simplest. Although relatively simple, it gives approximately good results close to the experimentally measured values of concentrations. Because of this, the Gaussian model is often implemented in software packages in use today, and are used to predict the spread of airborne pollutants. The Gaussian model is semi-empirical, because it contains parameters that are determined empirically. The following is the basic equation of the Gaussian model:

$$C_y(x,z)=\frac{Q}{2\pi u\sigma_x(x)\sigma_z(x)}\exp\left(-\frac{(x-ut)^2}{2\sigma_x^2(x)}\right)\left\{\exp\left[-\frac{(z-H)^2}{2\sigma_z^2(x)}\right]+\exp\left[-\frac{(z+H)^2}{2\sigma_z^2(x)}\right]\right\} \quad (2)$$

$$u_z=u_{10}\left(\frac{z}{10}\right)^p \quad (3)$$

Here $C_y(x, z)$ is the concentration of impurities along the *x-z* plane, u_z wind speed at altitude z, u_{10} time elapsed from emission of impurities from the source to the moment when the concentration is measured, velocity at 10 m altitude standardly measured, p – parameter which depends on atmospheric stability; $S_z(x)$ and $S_x(x)$ represent the dispersion coefficients of the impurity along the *z-x* axis, H s the height at which the source is located, Q is the radiation intensity of the source [g/s] (Jaćimovski et al, 2017). A graphical representation of the distribution of pollutants according to the Gaussian model is given in the following figure.

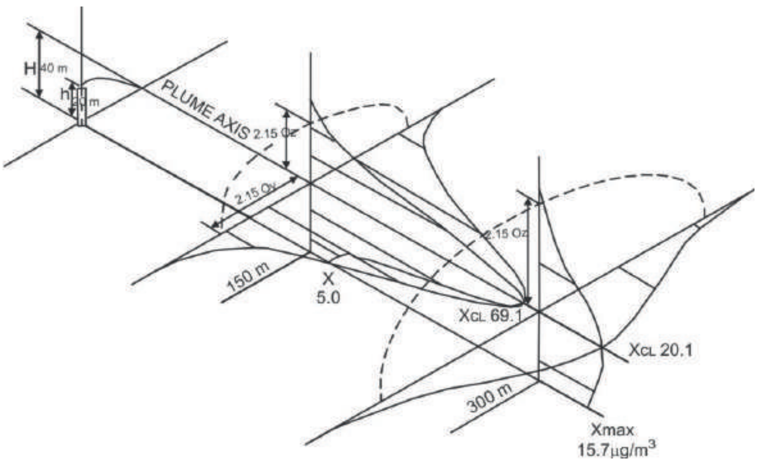

Figure 1. Example of pollutant distribution according to the Gaussian model

The values of the exponent p, according to the classes of atmospheric stability and according to the terrain conditions (urban or rural), are shown in Table 4.

Table 4. Values of the exponent p according to atmospheric stability classes

Class of stability	Rural area	Urban area
A	0,07	0,15
B	0,07	0,15
C	1	0,2
D	0,15	0,25
E	0,35	0,3
F	0,55	0,3

Impurity dispersion coefficients are determined according to the Brookhaven laboratory methodology (Hanna, Briggs, Hosker, 1982) as follows:

$$\sigma_x = \alpha x^{\beta}; \qquad \sigma_z = \gamma x^{\delta} \qquad (4)$$

The coefficients α, β, γ and δ depend on the stability of the atmosphere and are determined according to the following table.

Table 5. Atmospheric stability table

		α	β	γ	δ
VERY UNSTABLE	A	0,527	0,865	0,28	0,90
UNSTABLE	B	0,371	0,866	0,23	0,85
WEAKLY STABLE	C	0,209	0,897	0,22	0,80
		α	β	γ	δ
NEUTRAL	D	0,128	0,905	0,20	0,76
STABLE	E	0,098	0,902	0,15	0,73
VERY STABLE	F	0,065	0.902	0 12	0,67

According to the conditions shown in Table 3 and Table 5, by favorable conditions we mean the class of atmosphere stability B, by average conditions we mean the stability class D, and by unfavorable conditions we mean the stability class C.

Table 6. Adopted values of the parameters used to determine tear gas concentration according to the equation (2)

METEO CONDITIONS	SPACE	SPEED [m/s]		CLASS	Q[g/s]	z[m]	t[s]	H[m]
Favorable	Urban	u_z=6,02	u_z=1,64	B	55	1,8	60	0
	Rural	u_{10}=2,2	u_z=1,95		55	1,8	60	0
Average	Urban	u_{10}=6,5	u_z=4,61	D	55	1,8	20	0
	Rural	u_{10}=6,5	u_z=6,02		55	1,8	20	0
Unfavorable	Urban	u_{10}=1,8	u_z=1,28	C	55	1,8	60	0
	Rural	u_{10}=1,8	u_z=1,52		55	1,8	60	0

When calculating the concentration of impurities (of tear gas), we start with the following premises. We adopt that the source is on the surface of the ground, that is, $H = 0$ m. For the intensity of the source, we assume that it is 55 [g/s], and for the height at which we measure the concentration of tear gas, we take it to be $z = 170$ cm (the assumed average height of a human face). According to the atmospheric conditions in which the event takes place, we determine the appropriate wind speed at a standard height of $z = 10$ m and calculate the wind speed at a height of $z = 170$ cm. It is also considered whether the event we are analyzing takes place in urban or rural conditions. Atmospheric conditions also determine the dispersion coefficients according to the Brookhaven methodology. For the parameters thus adopted, it only remains to determine the duration of the event. The standard time for which the event is observed is $t = 60$ s. This applies to the favorable and unfavorable weather conditions. For average weather conditions, the time of event analysis is taken to be $t = 20$ s due to the high wind speed

FINDINGS

Tear concentration of tear gas in C[g/m3] for the favorable and unfavorable conditions in urban areas

According to the values of the parameters in Table 6, we have graphs which show that the horizontal axis is the distance x from the source in meters, and the vertical axis is the tear gas concentration in C[g/m3]. We believe that the event takes place in an urban environment under favorable weather conditions. The time of tear gas propagation is $t = 60$ s, while the speed is $u = 1.64$ m/s. With this in mind, the following graph is shown in Figure 2.

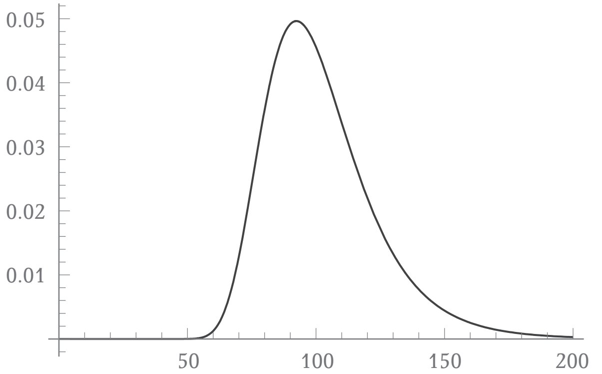

Figure 2. Tear gas concentration in C[g/m³] depending on the distance from the source of contamination in meters for favorable conditions in the urban area

For an urban area and unfavorable weather conditions, we consider that the wind speed and the time it takes for tear gas to spread are t = 60 s. The graph is given in Figure 3.

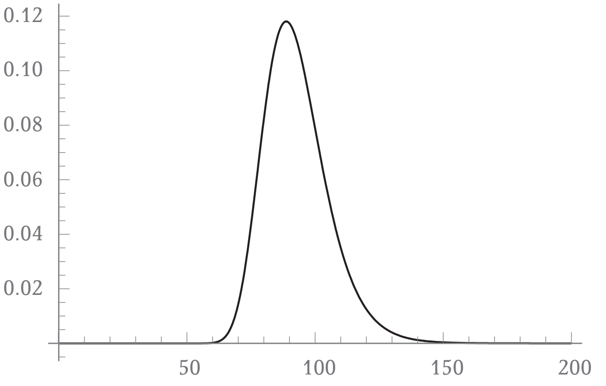

Figure 3. Tear gas concentration in C[g/m³] depending on the distance from the source of contamination in meters for unfavorable conditions in the urban area

By comparing the tear gas concentration in C[g/m^3] in an urban area, depending on the distance from the source of contamination in meters for the favorable and unfavorable conditions in an urban area, the following graph was obtained (Figure 4).

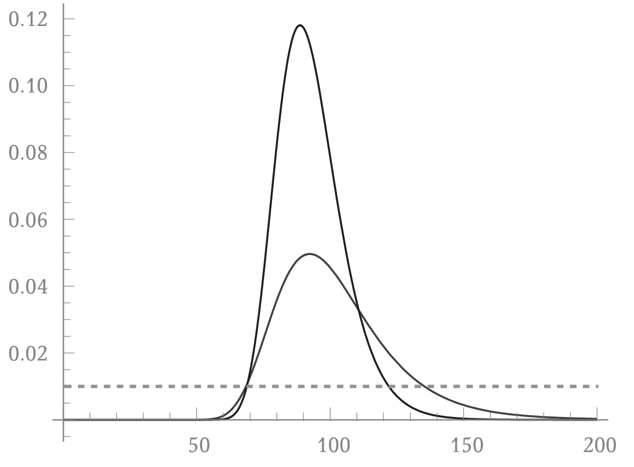

Figure 4. Comparison of the tear gas concentrations in C[g/m³] depending on the distance from the source of contamination in meters regarding the favorable and unfavorable conditions in the urban area

Black color represents favorable conditions, and blue color unfavorable conditions. The dashed line is the limit of intolerable concentration (incapacitation due to contamination). The area where the concentration is above the limit of incapacitation is $x_1 \in$(68,45m–135,28m) for the favorable weather conditions (which is a range of 66.83 m), while for the unfavorable weather conditions this area is je, $x_2 \in$(56,48m–106,73m), which is a range of 50.25 m. Figure 4 shows that the concentration for the unfavorable weather conditions is more pronounced (there is a higher peak) and that it is above the limit of incapacitation in a smaller area. Furthermore, a graphical representation of spreading for different times is as follows.

For the urban area and favorable conditions in it, the following graph is given (Figure 5), which compares tear gas concentrations in C[g/m³] depending on the distance from the source of contamination in meters and different time periods of contamination (t_1=60 s, t_2=75 s, t_3=90 s). The wind speed in all three cases amounts to u = 1,64 m/s.

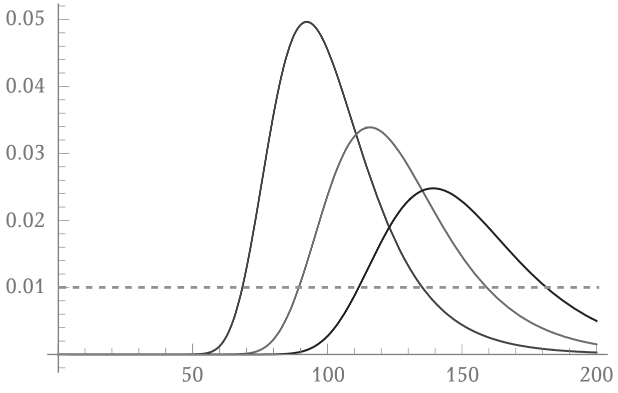

Figure 5. Comparison of the tear gas concentration in C[g/m³] depending on the distance from the source of contamination in meters and different duration of contamination (t_1=60 s, t_2=75 s, t_3=90 s) in the urban area for favorable conditions

Blue color represents t_1=60 s, red t_2=75 s and black t_3=90 s. The dashed line is the limit of intolerable concentration (hereinafter: incapacitation). Areas where the concentration is higher than the incapacitation threshold are as follows: $x_1 \in$(68,45m–135,28m), that is, the range of 66.83 m, $x_2 \in$(89,41m–159,14m), that is, the range of 69.73 m, and $x_3 \in$(111,65m–181,32m), that is, the range of 69.67 m. Bearing in mind the wind speed (1.64 m/s), the time of achievement, completion and duration of incapacitating concentration in these conditions are shown in the following table.

Table 7. Time of achievement, completion, and duration of incapacitating concentration in an urban area for favorable conditions

Area	Conditions and contamination time [s]	Time of achievement of incapacitating concentration [s]	Time of completion of incapacitating concentration [s]	Duration of incapacitating concentration [s]
Urban	Favorable conditions 60 s	41,74	82,49	40,75
	Favorable conditions 75 s	54,52	97,04	42,52
	Favorable conditions 90 s	68,08	110,56	42,48

For the urban area and unfavorable conditions, the following graph compares tear gas concentrations in C[g/m³] depending on the distance from the source of contamination in meters and different duration of contamination (t_1=60 s, t_2=75 s, t_3=90 s). The wind speed in all three cases is u = 1,28 m/s.

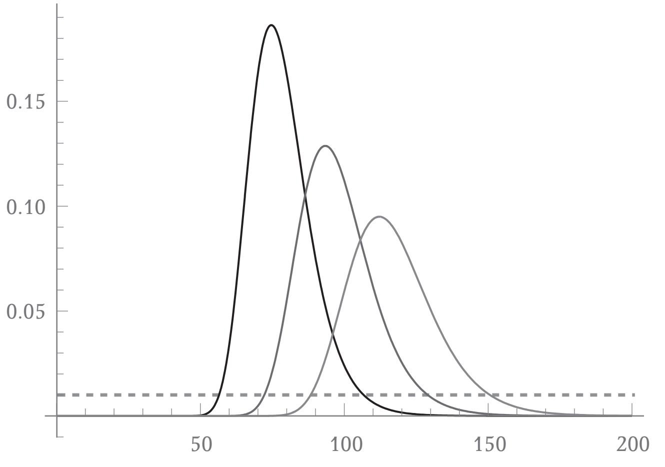

Figure 6. Comparison of tear gas concentration in C[g/m³] depending on the distance from the source of contamination in meters and different duration of contamination (t_1=60 s, t_2=75 s, t_3=90 s) in the urban area for unfavorable conditions

Black color is t_1=60 s, red t_2=75 s, and brown t_3=90 s. The dashed line is the limit of incapacitation.

Areas in which the concentration is higher than the limit of incapacitation are $x_1 \in (56{,}48\text{m}-106{,}73\text{m})$, that is, the range of 50.25 m $x_2 \in (72{,}20\text{m}-129{,}00\text{m})$, that is, the range of 56.80 m, and $x_3 \in (88{,}31\text{m}-150{,}63\text{m})$, which is the range of 62.32 m. It is noticed that the concentrations are more pronounced and that they have an effect in the smaller dimension areas than in the case of favorable weather conditions. Considering the wind speed (1.28 m/s), the time of achievement, completion and duration of incapacitating concentration in the same conditions are shown in the following table.

Table 8. Time of achievement, completion and duration of incapacitating concentration in the urban area for unfavorable conditions

Area	Conditions and contamination time[s]	Time of achievement ofincapacitating concentration [s]	Time of completion of incapacitating concentration [s]	Duration of incapacitating concentration [s]
Urban	Unfavorable conditions 60 s	44,13	83,38	39,26
	Unfavorable conditions 75 s	56,41	100,78	44,38
	Unfavorable conditions 90 s	68,99	117,68	48,69

Tear gas concentration in C[g/m3] for the favorable and unfavorable conditions in rural areas

For the *rural* areas, the tear gas concentration in C[g/m^3] depending on the distance from the source of contamination in meters for the favorable conditions is shown in the following graph. The time of tear gas dissemination is t = 60 s, while the wind speed is u = 1,95 m/s.

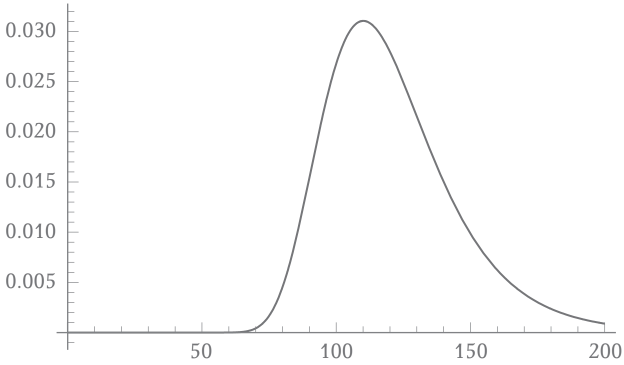

Figure 7. Tear gas concentration in C[g/m³] depending on the distance from the source of contamination in meters for favorable conditions in the rural area

For the *rural* areas, the tear gas concentration in C[g/m^3] depending on the distance from the source of contamination in meters for the unfavorable conditions is shown in the following graph. The time of tear gas dissemination is t=60 s, while the wind speed is u = 1,52 m/s.

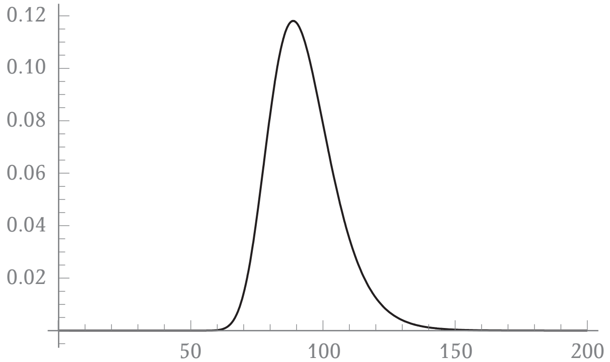

Figure 8. Tear gas concentration in C[g/m³] depending on the distance from the source of contamination in meters for unfavorable conditions in the rural area

By comparing the tear gas concentrations in C[g/m^3] depending on the distance from the source of contamination in meters for the favorable and unfavorable conditions in rural areas, the following graph was obtained.

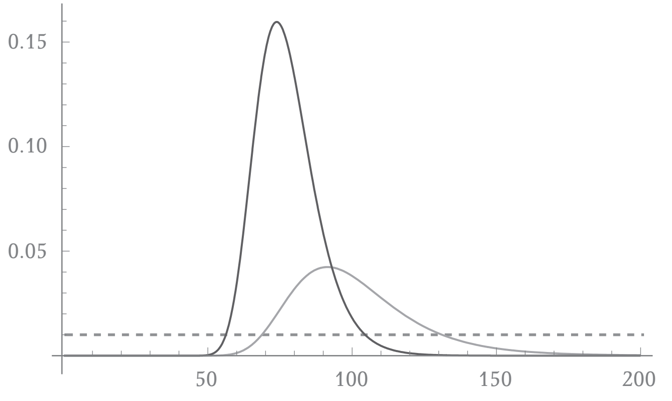

Figure 9. Comparison of tear gas concentrations in C[g/m³] depending on the distance from the source of contamination in meters for favorable and unfavorable conditions in the rural area

Green color represents the favorable conditions and orange the unfavorable conditions. The dashed line represents the limit of incapacitation. The area where the concentration is above the limit of incapacitation is $x_1 \in$(56,24m–104,51m) for the unfavorable weather conditions (48.27 m), and for the favorable weather conditions this area is $x_2 \in$(68,72m–131,19m), which is a range of 62.32 m.

For the rural area and favorable conditions in it, the following graph is given (Figure 10), which compares the tear gas concentrations in C[g/m³] depending on the distance from the source of contamination in meters and different duration of contamination (t_1=60 s, t_2=75 s, t_3=90 s). The wind speed is u = 1,95 m/s.

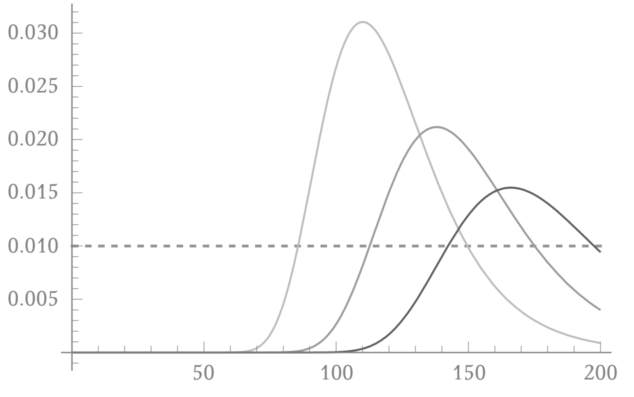

Figure 10. Comparison of the tear gas concentration in C[g/m³] depending on the distance from the source of contamination in meters and different duration of contamination (t_1=60 s, t_2=75 s, t_3=90 s) in the rural area reagrding favorable conditions

Green color represents t_1=60 s, brown t_2=75 s, and red t_3=90 s. The dashed line represents the limit of incapacitation The areas where the concentration is higher than the limit of incapacitation are x_1∈(68,72m–131,19m), which is a range of 62.47 m x_2∈(112,68m–171,1m) or a range of 58.42 m, and x_3∈(142,30m–197,55m) which is a range of 55.25 m, respectively. Bearing in mind the wind speed (1.95 m/s), the times of achievement, completion, and duration of the incapacitating concentration in the mentioned conditions are shown in the following table.

Table 9. Time of achievement, completion and duration of incapacitating concentration in the rural area regarding favorable conditions

Area	Conditions and contamination time[s]	Time of achievement of incapacitating concentration [s]	Time of completion of incapacitating concentration [s]	Duration of incapacitating concentration [s]
Rural	Favorable conditions 60 s	35,24	67,28	32,04
	Favorable conditions 75 s	57,78	87,74	29,96
	Favorable conditions 90 s	72,97	101,31	28,33

For the rural area and unfavorable conditions in it, the following graph is given (Figure 11), which compares tear gas concentrations in C[g/m^3] depending on the distance from the source of contamination in meters and different duration of contamination (t_1=60 s, t_2=75 s, t_3=90 s). The wind speed is u = 1,52 m/s.

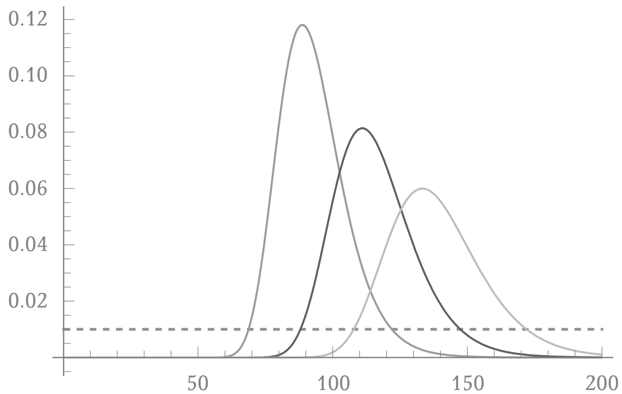

Figure 11. Comparison of the tear gas concentration in C[g/m³] depending on the distance from the source of contamination in meters and different duration of contamination (t_1=60 s, t_2=75 s, t_3=90 s) in the rural area for unfavorable conditions

Orange color represents t_1=60 s, purple t_2=75 s, pale green t_3=90 s. The dashed line is the incapacitation threshold. The areas where the concentration is higher than the incapacitation threshold are $x_1 \in$(68,77m–121,98m), which is a range of 48.27 m, $x_2 \in$(88,04m–147,40m) or a range of 59.36 m, and $x_3 \in$(107,83m–172,05m) which is a range of 64.22 m, respectively. Bearing in mind the wind speed (1.52 m/s), the time of achievement, completion and duration of the incapacitating concentration in the mentioned conditions are shown in the following table.

Table 10. Time of achievement, completion and duration of incapacitating concentration in the rural area for unfavorable conditions

Area	Conditions and contamination time[s]	Time of achievement of incapacitating concentration [s]	Time of completion of incapacitating concentration [s]	Duration of incapacitating concentration [s]
Rural	Unfavorable conditions 60 s	37,00	68,76	31,76
	Unfavorable conditions 75 s	57,92	96,97	39,05
	Unfavorable conditions 90 s	70,94	113,19	42,25

Tear gas concentration in C[g/m3] for average weather conditions in urban and rural areas

For average weather conditions, a time interval of *t*=20 is taken due to the high wind speed. For the urban areas, the wind speed is u = 4,61 m/s, and u = 6,02 m/s is for rural areas. A graph of the distribution of the tear gas concentrations for urban areas is given in Figure 12, and for rural areas in Figure 13.

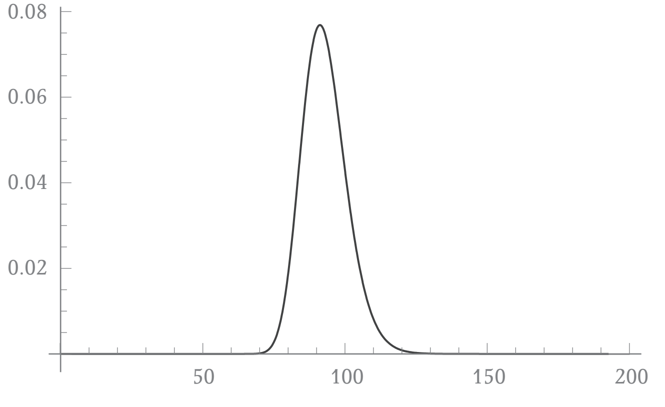

Figure 12. Distribution of the tear gas concentrations for average weather conditions in the urban area

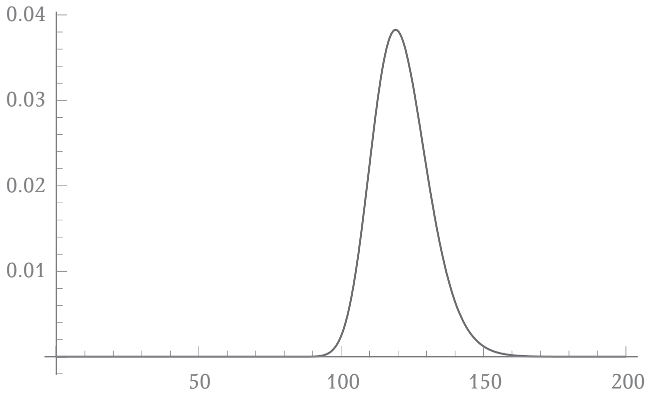

Figure 13. Distribution of the tear gas concentrations for average weather conditions in the rural area

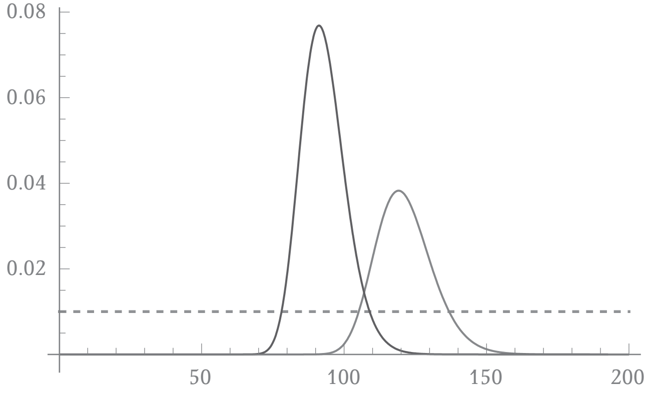

Figure 14. Distribution of the tear gas concentrations for average weather conditions; blue color represents an urban area, while red color represents a rural area

The areas where the concentration is higher than the incapacitation threshold under average weather conditions are $x_1 \in (78,05\text{m}-108,07\text{m})$ which is a range of 30.02 m and $x_2 \in (105,16\text{m}-136,87\text{m})$ which is a range of 31.71 m, respectively. Bearing in mind the wind speed (4.61 m/s), the times of achievement, completion, and duration of the incapacitating concentration in an urban area are shown in the following table.

Table 11. Time of achievement, completion, and duration of incapacitating concentration in the urban area for average conditions

Area	Conditions and contamination time [s]	Time of achievement of incapacitating concentration [s]	Time of completion of incapacitating concentration [s]	Duration of incapacitating concentration [s]
Urban	Average conditions 20 s	16,93	23,44	6,51

On the other hand, bearing in mind the wind speed (6.02 m/s), the time of achievement, completion, and duration of incapacitating concentration in a rural area are shown in the following table.

Table 12. Time of achievement, completion, and duration of incapacitating concentration in the rural area for average conditions

Area	Conditions and contamination time [s]	Time of achievement of incapacitating concentration [s]	Time of completion of incapacitating concentration [s]	Duration of incapacitating concentration [s]
Rural	Average conditions 20 s	17,47	22,74	5,27

DISCUSSION

Based on the graphs and tables, it is obvious that the concentrations above the value of incapacitation are more pronounced in average weather conditions, they are achieved quickly and last short time and have an effect in a shorter distance (about 30 m). the maximum values are higher in urban areas. Also, the maximum data for the average weather conditions are lower than in the case of unfavorable weather conditions, but higher than in the case of favorable weather conditions. Additionally, the length of the area in which the concentration is above the incapacitating concentration is almost twice as long in the case of favorable weather conditions than in the case of average weather conditions, and slightly higher than in the case of unfavorable weather conditions.

A cloud of contaminants is formed during the emission of smoke for 30-40 seconds. The cloud thus formed is transmitted by wind currents of certain direction and speed. Depending on whether the contamination takes place in an urban area or a rural area, or whether the conditions are favorable, average or unfavorable, the contamination of a certain area occurs (Table 13) in a certain period of time (Table 14).

Table 13. Spatial characteristics of the contaminated space [m]

Area	Conditions and contamination time [s]	Upper limit [m]	Lower limit [m]	Range [m]
Urban	Favorable conditions 60 s	135,28	68,45	66,83
	Favorable conditions 75 s	159,14	89,41	69,73
	Favorable conditions 90 s	181,32	111,65	69,67
	Unfavorable conditions 60 s	106,73	56,48	50,25
	Unfavorable conditions 75 s	129	72,2	56,8
	Unfavorable conditions 90 s	150,63	88,31	62,32
	Average conditions 20 s	108,07	78,05	30,02
Rural	Favorable conditions 60 s	131,19	68,72	62,47
	Favorable conditions 75 s	171,1	112,68	58,42
	Favorable conditions 90 s	197,55	142,3	55,25
	Unfavorable conditions 60 s	104,51	56,24	48,27
	Unfavorable conditions 75 s	147,4	88,04	59,36
	Unfavorable conditions 90 s	172,05	107,83	64,22
	Average conditions 20 s	136,87	105,16	31,71

Table 14. Time characteristics of the contaminated space [s]

Area	Conditions and contamination time [s]	Time of achievement of incapacitating concentration [s]	Time of completion of incapacitating concentration [s]	Duration of incapacitating concentration [s]
Urban	Favorable conditions 60 s	41,74	82,49	40,75
	Favorable conditions 75 s	54,52	97,04	42,52
	Favorable conditions 90 s	68,08	110,56	42,48
	Unfavorable conditions 60 s	44,13	83,38	39,26
	Unfavorable conditions 75 s	56,41	100,78	44,38
	Unfavorable conditions 90 s	68,99	117,68	48,69
	Average conditions 20 s	16,93	23,44	6,51
Rural	Favorable conditions 60 s	35,24	67,28	32,04
	Favorable conditions 75 s	57,78	87,74	29,96
	Favorable conditions 90 s	72,97	101,31	28,33
	Unfavorable conditions 60 s	37,00	68,76	31,76
	Unfavorable conditions 75 s	57,92	96,97	39,05
	Unfavorable conditions 90 s	70,94	113,19	42,25
	Average conditions 20 s	17,47	22,74	5,27

The use of chemical agents by law enforcement in controlling civil disorders in the above six specific conditions (2 (two) areas * 3 (three) weather conditions = 6 specific conditions). These conditions are not comparable (the area is urban or rural, etc.), which means that some conditions exclude others. Therefore, the subject of discussion is the dispersion of contaminants in certain areas and conditions, depending on the duration of contamination (60, 75, and 90 s).

In the urban area, after the emission of smoke from the grenade, in the next 60s, the incapacitation concentration of tear gas is achieved at distances of 68.45 m (in 41.74 s), up to 135.28 m (it reaches the end point in 82.49 s), which means that the same concentration extends in the length of 66.83 m and lasts for 40.75 s. If a decision maker wants to achieve such an incapacitating effect on the target, in the favorable weather conditions, including the time of the day, then it is necessary for the tear gas emission line to be perpendicular to the wind direction at a distance of 68.45 m from the activated M1 hand grenade. Symmetrically to this finding and opinion, it is possible to predict and achieve other effects that are considered in this paper.

Such predictions should be made available to decision makers and those who need to implement them. However, it is necessary to create preconditions for determining the weather conditions in the area where chemical agents will be used. Generalized weather forecasts coming from distant places in relation to the area where chemical agents will be used do not allow this type of the prediction of the effects of their use. In order for that to be possible, the company, as the basic police tactical unit for suppressing civil riots, needs to be equipped with a drone, with meteorological sensors, so that it can collect the necessary data at a standard height of $z = 10$ m.

By wireless connection, this drone must be connected to the command and information system available to the company commander, which contains an application (for example "ALOHA") to apply the Gaussian model in order to predict the spread of air pollutants (device minimization and mobility trends suggest that this feature may also be used on a mobile phone). At the same time, the data must be enabled to automatically enter the application, which allows passing through and exit from it in the form of spatial and temporal features of the use of chemicals, starting from the direction of the line of emission of chemical agents and its distance from the nearest position of civil disorder participants.

In technical terms, it is necessary to provide appropriate logistical support for such a technical system. On the other hand, the proper use of such a technical system requires training of instructors, users, the training activities of units, designing training programs, the introduction of such contents in the curriculum for relevant subjects (for example, police technology, police tactics and managerial theoretical-cognitive disciplines). Finally, depending on the workload, it is necessary to envisage, at the company level, a police officer whose one or more responsibilities would include drone piloting (a drone operator's duty).

CONCLUSION

Strict and general rules cannot predict, in a precise and safe way, the use of chemical agents by law enforcement in controlling civil disorders. Their application makes it possible to roughly predict the contamination of the space, without predicting the concentrations that will be achieved when applied, as well as the time it takes for certain concentrations to be achieved and their duration. In order to overcome such shortcomings, it is recommended to use software packages based on the Gaussian model to predict the dissemination of airborne pollutants, in this case the chemical substance CS.

This paper answers the questions posed under the conditions mentioned in the introduction (an urban area or a rural area, favorable, average or unfavorable meteorological conditions, combined with the time of the day, the contamination of space by activating one hand-thrown grenade M1): 1) which concentrations of contaminants are achieved at certain distances, especially at which distances incapacitating concentrations are created and how far they can travel (given in Table 13, depending on the duration of contamination) and 2) how long it takes for the incapacitating concentrations of contaminants to be created and how long they last (given in Table 14, depending on the duration of contamination).

Based on these conclusions, recommendations were made for the management (especially the use of drones with meteorological sensors for determining weather conditions as variables necessary for the application of the Gaussian model, including recommendations regarding their procurement and maintenance, as well as training) and the tactics of the engagement of police units in situations in which the chemical agents are used (especially regarding distances, that is, the time of achievement and duration of incapacitating contamination with chemical agent CS). Additionally, recommendations for future research in this area have been given.

This research included contamination times of 60, 75 and 90 s, not shorter or longer times, which makes room for further research. The widths and heights of the contaminants, depending on the conditions of its emission, have not been problematized in this paper, which means that future research on this topic may include these two dimensions of the dispersion of tear gas contaminants.

The chemical agents CN and CR are also not considered, so their dispersion can be investigated using this or similar methodology. The CS emission was considered by activating one type of a hand grenade, rather than activating more such agents, or more similar agents (for example, several different types of hand grenades), simultaneously or sequentially (at different intervals between two consecutive activations), nor by combining several types of devices for emitting chemical substances (chemical rifles and pistols, smoke boxes, sprays, etc.). Additionally, this paper considers only the use of chemical agents by law enforcement in controlling civil disorders, but not during the performance of other security tasks.

Finally, in addition to the Gaussian model, it is possible to use other deterministic models, such as Lagrangian and Eulerian models, in modeling the dispersion of chemical agents by law enforcement in controlling civil disorders. Additionally, the data obtained using the Gaussian model can be compared with the data obtained by other models, through experimental data, which would determine the most valid model regarding their application in predicting the dissemination of chemical agent CS and other chemicals, in different conditions. Therefore, future research and the application of this methodology can fill these gaps in knowledge in this area.

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Paper received on: 2/2/2022

Paper accepted for publishing on: 7/7/2022