Mortise terrorism on the main pipelines

V A Komarov¹, N N Nigrey², D A Bronnikov¹ and A A Nigrey¹

¹Omsk State Transport University, Omsk, Russia
²Siberian State Automobile and Highway University, Omsk, Russia

Abstract. The research aim of the work is to analyze the effectiveness of the methods of physical protection of main pipelines proposed in the article from the "mortise terrorism" A mathematical model has been developed that made it possible to predict the dynamics of "mortise terrorism" in the short term. An analysis of the effectiveness of physical protection methods proposed in the article to prevent unauthorized impacts on the objects under investigation is given. A variant of a video analytics system has been developed that allows detecting violators with recognition of the types of work they perform at a distance of 150 meters in conditions of complex natural backgrounds and precipitation. Probability of detection is 0.959.

1. Prediction of terrorist threats in the main pipelines

Accident statistics on pipeline transport facilities indicates presence about problematic issues in this human activity [1]. Along with traditional causes of accidents: corrosion, natural influence, human errors, etc. became an essential role to play external influences on product pipeline (Table 1).

Under external influences refers to third party activities (mechanical action of building and earth-moving equipment, tie-in to theft pumped product, sabotage acts). Noteworthy is a significant violations percentage in Russia. The number of registered unapproved inserts in the country in 2005 exceeded 900, then there was a decrease this level. Incuts became less and less, «but began to steal more». In case we entered the criminal community, who have managed to turn oil theft from pipelines in largest sector of shadow business [3]. In [4] this type activity named «mortise terrorism».

Another reason (at this stage mostly potential) of the growth of mentioned influences – classical terrorism. Along with the terrorist acts aimed at achieving political goals (Budennovsk, New York, Moscow and others.) a technology that would cause economic damage starts to develop (blowing up oil pipelines in Iraq, Nigeria, pipelines in Russia). The question about anti-terrorist protection of the pipeline transportation facilities was raised in «Transneft» [5, 6]. According to predictions in near future intensity of terrorist acts on the objects will increase due to relative safety of their implementation for executors, availability of sales stolen resources market, problems with moral health of society and level of living population, their high efficiency in terms of economical losses and political consequences. The well-known Lancaster’s , Volter’s and Holling - Tanner’s models were used for making predictions. However, these models do not take into account influence of state and economic factors. For a more adequate model should include type of

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\begin{align*}
\frac{dN_1}{dt} &= f_1(GDP, I / C) - f_2(MH_{so} / MH_{si}) - \frac{\alpha_i}{\alpha_i} \beta_{2} N_1(t), \\
\frac{dN_2}{dt} &= f_3(PC / L) - f_4(DS / L) - \frac{\alpha_i}{\alpha_i} \gamma N_1(t),
\end{align*}
\]

(1)
where \( N_1 \) — number of attacks on the protected object, \( GDP \) — gross domestic product per capita in the past year, \( I/C \) — ratio of average income of the operation to the cost to carry it out, \( MH_{90} / MH_t \) — ratio of population moral health (in the region) in the 90th and current years respectively; \( \alpha_1 \) and \( \beta_1 \) level of proficiency and technical equipment of the attacking side, \( \alpha_2 \) and \( \beta_2 \) level of proficiency and technical equipment of the defenders, \( \gamma \) — factor of interaction between defenders and attackers (inversely proportional to size / length / area of protected object), \( N_2 \) —number of object defenders, \( PC \) — protection cost, \( L \) — total losses from attacks on protected object, \( DS \) — defenders salary.

\( GDP \) characterized poverty of society, function \( f_1(GDP = \text{const, } I/C) \) — the proportion of people ready to go on offense, depending on expected income and having sufficient knowledge to commit a crime in this activity sphere.

**Table 1.** Information about accidents reasons on main pipelines in various world regions.

| Country (region) | External influence | Equipment defect | Corrosion | Natural influence | Human error | Other |
|------------------|--------------------|------------------|-----------|------------------|-------------|-------|
| Russia           | 63% (17%)          | 19% (30%)        | 6% (50%) | – (–)            | 12% (3%)    | –     |
| USA              | 23% (25%)          | 20% (19%)        | 23% (23%)| 4% (10%)         | 7% (2%)     | 23% (21%) |
| West Europe      | 37% (50%)          | 25% (16%)        | 28% (15%)| 3% (7%)          | 7% (5%)     | – (7%) |

Obviously when \((I/C) \leq 1\) value of function \( f_i(\ldots) = 1 \) (there is no point in carrying out operation without receiving any profit; factor of "revenge" is taken into account). Curve \( f_i(\ldots) \) has a saturation point when the resource of society members able to commit an offense specified type is exhausted. For communities, characterized by different ratios of limiting factors, the curve shape is maintained, change its coefficients. \( f_1(GDP = \text{const, } I/C) = a_1 / (1 + b_1 \exp (– c_1 I/C)), \) where \( a_1 \) — coefficient determining part of society, potentially ready to move into camp of offenders from vested interests. Coefficients \( a_1, b_1, c_1 \) determined consider the expert technologies obtained in previous year's GDP.

Function \( f_2(MH_{90} / MH_t) = (MH_{90} / MH_t) f_1(\text{I/C}) \) describes law-abiding population, its cultural level and legislative base for combating relevant type of crime. \( MH_t \) acts as an integral index, evaluated according to statistics (in terms of characterizing social tension in society). Functions \( f_i, f_t \) are special cases of logistic curves.

It is obvious that protection cost \( PC \) will be greater, then more \( N_2 \). Total losses from attacks \( L \) increase with number of attacks, i.e. with increasing \( N_1 \). One of possible functions \( f_5(PC, L, N_1, N_2) \), considering nature of its logistics:

\[
f_5(PC, L, N_1, N_2) = a_3 \exp \left[ \frac{LN_1}{PC^N_2} - b_3 - c_3 \right] \left[ 1 + \exp \left( \frac{LN_1}{PC^N_2} b_3 - c_3 \right) \right],
\]

where \( a_3, b_3, c_3 \) — coefficients of curve.

By detectable \( \frac{dN_i(t)}{dt} \), current expenditure on protection and object losses from attacks on him, the value of \( I/C \), determined by a survey of population adjacent to object and track ratio \( MH_{90} / MH_t \) assesses state of protection \( f_i \) and its difference from optimum \( I_{opt} \) (equality of defense costs and losses caused by attacks to object). By \( I_{opt} \) specifies requirements for probability of attacks detection and false alarms, which should provide a security service object.

The results modeling dynamic system, described by equations (1) for different values of function arguments \( f_i \) and \( \alpha_1, \beta_1 \) allowed to make following conclusions.

In the case of low-skill and technical equipment of defenders \( \alpha_2 \) and \( \beta_2 \) relatively similar indicators confrontation is periodic. Low discipline and financing of security forces do not allow management of organization to respond quickly to changing situations and entail excessive losses from terrorist activities and maintenance of excess defenders state. Even approach of indicators \( \alpha_2 \) and \( \beta_2 \) to
maximum possible value does not fully solve the problem of counteraction to terrorist attacks, the system quickly reaches a steady non-zero state. The determining factor in this case is the level of society moral health \(MH\). Considering this, as well as exponential growth of content defenders value while increasing \(\alpha_2\) and \(\beta\), we arrive in general case to conclusion about inappropriate choice of maximizing strategy level of protection object against terrorist threats. Optimum protection of economy objects from such threats, the strategy should include the interaction between the state and the object aimed at improving preventive public welfare, moral health of society and fight against crime.

We illustrate the efficiency of use "is not an optimal strategy" in particular example. Given fundamental laws of society in terms of population growth, dwindling natural resources and increasing pollution of environment [7], should be anticipated decline \(GDP\) and \(MH\) and increase in growth attacks on sources of resources. This view is justified in [8], in which the major reasons contributing to development of terrorism attributed decline in the living standards of social and professional groups, deepening of social differentiation, provoking political, ethnic and social conflicts. It should be determined by security policy relevant economic facilities from terrorist threats in near future. Solution to this problem for main pipelines emerges when considering the special case arising from the model (1) and reflecting interaction in system "terrorist – main product pipeline protection system – police," which can be represented as a system of four equations

\[
\begin{align*}
\frac{dN_p}{dt} &= r_{po} \left(1 - \frac{N_p}{N_{po} + N_{po}}\right) N_p - \alpha_p p_r m_r p_{ml} N_p N_M + r_{p2}; \\
\frac{dN_p}{dt} &= \alpha_p \left(\frac{N_{p}}{g_p} - N_B\right) - \frac{N_p}{g_p} p_r \alpha_p; \\
\frac{dN_D}{dt} &= r_{s0} \left(\frac{D_B(-t_s)}{v_s D_0}\right)^{k_{s0}} - r_{s1} \left(\frac{D_s}{v_s D_0(-t_s)}\right)^{k_{s1}}; \\
\frac{dN_M}{dt} &= \frac{N_p}{g_p} (-t_{M}) p_B (-t_{M}) \alpha_p r_{M0} - r_{M1} N_M + r_{M2} N_p,
\end{align*}
\]

where \(N_p(t)\) – number of terrorist attacks at time \(t\), \(N_B\) – number of attacks on the object, \(N_D\) – number of pipeline protection elements, \(N_M\) – number of employees involved in investigation of criminal activity on main pipelines, \(r_{po}\) – coefficient of information distribution (F. Bass [9]) among members of society ("viral" factor), \(N_{po}\) – capacity of environment in which the “idea of product theft” will be distributed [10], \(\alpha_p\) – average number of terrorist groups attacks on the object per time, \(p_r\) – probability of attack detection, \(m_r\) – probability to arrest terrorists, \(p_{ml}\) – conviction probability to the detained terrorists, \(r_{p2}\) – growth coefficient of the number of product theft ideas adherents, \(g_p\) – average size of terrorist group; \(r_{s0}, r_{s1}\) – coefficients of growth and cost reduction to protect the object; \(k_{s0}, k_{s1}\) – protection strategy coefficients that determine FAR and FRR limits of the protection system, \(D_B\) – loss from an attack at time \(t\), \(D_s\) – cost of protection, \(v_B\) – loss of income as a result of attacks, \(v_s\) – ratio of losses from attacks to cost of object protection, \(t_{M}\) – delay of response to the registered attack, \(r_{M0}, r_{M1}\) – respectively, growth and reduction rate of employees number involved in investigation of attacks on the protected object, \(r_{M2}\) – coefficient of employees growth at activity changes in sales of stolen product.

Model adequacy (2) is checked by comparing results of process simulation "mortise terrorism" in Samara region in period from 2000 to 2001, with actual data obtained from [11] – [19]. Figures 1, 2 allow us to estimate efficiency of our model to generate predictions in this segment of pipeline transportation safety.
The model reflects integrated parameters describing interacting parties and does not consider stochastic component of real confrontation process. Therefore, it should only be used for predictions of terrorist attacks in major entities (country, region, major oil company). Long-term predictions based on use of model, predicting a new cycle of significant growth in terrorist attacks on pipelines, followed by recession at the end of third decade (Figure 3).

Figure 1. Results of modeling and statistics according to number of detected incuts.

Figure 2. The results of modeling and statistics on number of convicted people.

Figure 3. Modelling opposing sides financial indicators until 2029 while maintaining the current level of intrusion detection probability: 1 – the annual total costs, billion rubles, 2 – the annual damage from incuts, billion rubles, 3 – annual defense costs, billion rubles.

Actual protection cost and size of losses from incuts are confidential. Therefore, data in Figure 3 reflect trends in defense costs and damage caused by theft of product in a hypothetically assumed figures at the initial time (2000).

This model provides a single realization of random process at specified rates modeling system. For the degree projected estimate scattering we must move on to development of stochastic models. One embodiment of constructing such models may be based on the use of controlled Markov processes. However, to identify development trends of studied process the information obtained using the model (2) is sufficient.

Computational experiments using model (2) also allow determining the structure of physical protection from terrorist threats. Figure 4 shows financial indicators associated with operation facility, which is subject to terrorist attacks.
The argument is taken as probability detected attacks. The curves represent a well-known principle of system analysis: less spending is laid on security created by system, the greater loss to be expected when it is operating. The minimum point «total loss» curve defines a rational protection level.

The curves represent one of possible cost ratio. Reducing cost of object protection or increase losses from attacks reduce minimum point \( p_v = 1 \).

The probability of attack detection \( p_v \) depends on a number of security elements (security number) \( N_p \), their qualification level. In a simplified (illustative) case value \( p_v \) estimated as follows.

We take attitude of «loss from the attack / defense costs» zero. Then \( p_v = 0 \). The owner of object determines at which excess losses of over-spending \( q \) protection is not deemed satisfactory. When a linear dependency \( p_v (q) \) for \( q = 10 \) value \( p_{v_{opt}} \) exceeds \( 0.9 \); and ratio of cost protection for losses from attacks equals \( 1 \). Current costs and losses in organization must be known. All these data allow us to estimate a current level of object protection \( (p_v) \), necessary resources for transition to mode \( p_{v_{opt}} \), qualification level and number of defenders, as well as to determine the structure of physical protection system, providing \( p_{v_{opt}} \).

2. The structure of physical protection system from terrorist threats

To resolve the issue of quantitative and qualitative composition of technical protection suggested using a well-known method of hierarchy analysis T. Saaty [20]. Implementation of this method requires knowledge of threat types, probability of their implementation assess effectiveness threat prevention engineering and technical means. For main pipelines question in the open literature is not presented. However, variant indicative promising system for reducing number of attacks, ending positive outcome, emerges from analysis of published materials in recent years. The peculiarity of research problem: occurrence an unauthorized person (group of persons) in a strip ± 25 m from pipeline is considered a precursor to a possible terrorist attack. In addition to human disturbance of physical fields in controlled area caused by animals, vehicles, wind factor (through the vegetation, power support), turbulent motion of pumped oil, etc. It is necessary to solve problems detected in the background noise (interference) and classification of invading object (subject).

If a person is detected and recognized, it solves second part of problem – finding his intentions in contact with product lines. If any such intentions notified security service of the monitored object. Statement of remote subject’s intentions determination comes from US Army. This task entrusted to company «Irvine Sensors Corporation» [21]. Automation of detection processes and pattern recognition – a feature of almost all objects for extended protection research. These tasks for detection and pattern recognition offered to solve with a help of video-seismic- vibrotechnology – computer data analysis techniques in order to obtain interesting information about protection without human intervention using optical respectively seismic and vibration signals. During 2008 to 2014 highest number of publications in electronic indexing systems Web of Science, Scopus, RSCI, publications...
seismoanalysis (115). The diagram in Figure 5a shows distribution of these publications on areas of research, in Figure 5b – the percentage of different physical channel.

![Diagram showing distribution of publications on seismoanalysis and research areas.](image)

**Figure 5.** Distribution of publications on seismoanalitics, presented in Web of Science, Scopus, RSCI 2008–2014 g for the period (a), and distribution research by use different channels (b).

Today prevailing view of preference for monitoring use distributed fiber optic sensors. With their help determined spatial distribution of temperature and mechanical strain in pipeline environment.

Local inhomogenities these figures give rise to Raman components (Raman or Brillouin). At time of propagation these components (the Stokes or anti-Stokes) scattering of place (active radar principle) tried on the location of this inhomogeneity.

It is argued that this type of system will help to detect leakage from pipeline an intensity 50 ml / min on highways length 16.85 km. [22] This principle is basis of "leakage detection systems and monitoring activities" Omega. [23].

A detailed analysis of possibility wider use distributed fiber optic systems as problem solution has led to more cautious conclusions. Strong influence of acoustic and seismic noise of natural and artificial origin on decisions taken narrows the scope of their application [24, 25]. Development direction of such systems is focused on complexity data processing algorithms. Australian company Future Fiber Technologies offers a system, which is based on algorithmic support costing over 100 thousand dollars [26].
The diagram in Fig. 5a illustrates the area of interest in development of fiber-optic systems. Is preserved uncertainty about classification problem solving intrusion into protected zone and the species held on her work. Designated in [27] requirements for detection probability of unauthorized crossings protected perimeter (0.95), while ensuring absence of occurrence false alarm for 250-500 hours (average requirements) in the works are not met.

Not worked out issues combating prepared offenders (e.g., installation in ground two seismic generators greatly reduces system parameters in area between them). Classic way overcoming encountered difficulties – use the rule: "If the use of one type detection system is unsatisfactory, need to complexing tools with different physical principles of detection. Applications 2 with mediocre performance is more productive rather than one with higher rates".

On linear part of underground main pipelines main operation is detection formation of pit to access a pipe surface. It can be provided by using vibro-acoustic system based on excitation pulses in pipe shell subsequent analysis of recorded signals at a predetermined distance from place of their formation [28]. Each pulse has a small piece of information about the state of object, but combination of such pulses provides a reasonable probability of errors 1-st and 2-nd kind [29].

Available estimates detection range of pits on control object (including product leakage) separate link «generator – detector» as used by shell method buzzer pipe fluctuate in range of 2–5 km. It will take about 0.5 billion rubles to Russian pipelines to reach this kind of control. This figure is 25 times lower than the estimated economic costs of loss transported product (a significant portion coming into Arctic Ocean from Russia – more than 500 tonnes per year shall be made rivers [30].

The effect of both fiber optic and vibro-acoustic systems can be estimated using a general theorem on repeated experiments. Probability hypothesis if the probability derived from $N$ independent experiments is based on analysis generating function

$$
\varphi_N(z) = \prod_{j=1}^{N} (q_j + p_j^* z),
$$

where $q_j = 1 - p_j$; $p_j$ – probability hypothesis according to $j$-th channel. Coefficient of $Z^0$ probability $p_{0N}$ that considered hypothesis is not true. Then, with probability $q_{0N} = 1 - p_{0N}$ it recognized fair. for a combination of $p_j = 0.86$ and 0.93 total probability detection will be 0.99.

Strong influence of seismic and acoustic noise natural and artificial origin limiting application of fiber optic warning system emergencies in controlled facilities. With reference to pipeline transport as these areas around the pumping station at the intersection of pipeline with a car or a railway line at a close distance from the paved roads or watercourses. For these categories other preferred embodiments of complex systems, «video analytics – vibroacoustic», «video analytics – seismic (at point geophones) – vibroacoustic» and others.

Developed version video analytics systems allow to detect intruders with recognition they perform types of work at a distance in 150 meters in a complex natural backgrounds and precipitation. Installed detection probability – 0.959 [31].The effectiveness of integrated system is illustrated in following figures. If each of subsystems is characterized probabilities 0.5 and 0.9, the integrated system – 0.75 and 0.99 and three subsystems – 0.87 and 0.995.

3. Conclusion

Tendency growth of steal product volumes justified reasons systemic nature. System-wide laws of growth in social structures are exponential. Combating theft can slow down this process, but in short-term trend of growth losses will not change. Aware of need to improve physical protection of pipelines for prevention emergency situations is carried out in a lower pace to meet the existing needs of problem. One reason for this is lack of study basic issues fundamental nature. A notable step in solving this problem would be creation a comprehensive system of physical protection, based on presentation of concept formation it structure. To do this, assess the potential of fiber identification, vibroacoustic, seismoanalytic systems, estimating their limiting ability to cope with the tasks.
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