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MODELOWANIE RYZYKA BEZPIECZEŃSTWA - KONCEPCJA PRZETRWANIA

Streszczenie: Problemy bezpieczeństwa zyskują najwyższy priorytet we współczesnym społeczeństwie. Podstawą dla badań kryminalistycznych są relacje pozwanych/oskarżonych. Aby wykryć ewidentne czynniki wpływające na prawdopodobieństwo wyjaśnień/zeznań pozwanych na różnych etapach oraz interwałach czasowych prowadzonego śledztwa, zastosowano analizę przeżycia. Zastosowano tzw. tabele życia, aby zbadać zagrożenia związane z przyznaniem się oraz aby badać wzajemne zależności pomiędzy różnymi komponentami procesu przyznania się do winy - pomiędzy oskarżonymi, rozważając także wyzwania związane z niekompletnymi danymi. Dodatkowo, zastosowano model regresji Coxa, aby przewidzieć prawdopodobieństwo przyznania się oskarżonego.

Słowa kluczowe: ryzyko bezpieczeństwa, analiza przeżycia, model Kaplana-Meiera, model proporcjonalnego hazardu Coxa.

THE CONCEPT OF SURVIVAL IN THE MODELLING OF SECURITY RISKS

Summary: Security concerns have emerged as a paramount priority in contemporary society. The cornerstone of the evidentiary foundation in criminal investigations is the confession of the defendant. To uncover less apparent factors influencing the likelihood of a suspect's confession at various stages or time intervals throughout the trial, survival analysis was employed. Life tables were employed to examine the risks associated with confessions and to explore the interplay between various components of the guilty plea process among the accused, considering the challenges posed by incomplete data. Additionally, a Cox regression model was constructed to predict the likelihood of a defendant confessing.

Keywords: security risks, survival analysis, Kaplan-Meier model, Cox proportional hazards model.

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1. Formulation of the problem

One of the main pieces of evidence of the suspect's guilt is his confession of committing a crime. However, according to the estimates of the American project "The Innocence Project", about 25 percent of suspects, whose innocence was proven just after conviction, admitted their guilt [1]. The risk of false confessions may result in confessional evidence being inadmissible in the criminal trial. In addition, investigative bodies require a clear understanding of non-obvious interrelationships between the elements of the decision-making process by suspects to plead guilty to criminal offenses. Information about the time intervals of the pre-trial investigation where the accused are most likely to give confessions, can provide significant support during the trial and reduce the probability of criminal justice errors due to the lack of experience and analytical tools. In order to prevent and solve criminal offenses successfully, justice authorities should use data science, mathematical modeling and innovative analytical and information support.

2. Analysis of recent research and publications

Scientific investigations on the applied application of information technologies and mathematical modeling methods for optimal decision-making support in the field of criminal justice are extremely rare and touch upon only specific problems of analyzing complex arrays of big data under conditions of uncertainty [2-7]. In particular, the analysis of the effects and risks of the confession of the accused is carried out only in relation to certain aspects of this process. In most scientific papers, the problem of confession's role in the criminal process is investigated or various aspects of the voluntariness and truthfulness of the confession are analyzed [8-13]. The absence of scientific analysis of criteria, signs and hidden peculiarities of the process of guilt admission by the accused in the commission of the criminal offense is the reason for mistakes made by police while investigating criminal cases. In order to assess such risks, diverse investigations of the process of decision-making by the accused to plead guilty to a criminal offense are required.

3. The objective of the paper

Analysis of the risk factors of the confession of those accused of committing a criminal offense, determination of the probability of possible guilt admission after the end of the trial in criminal proceedings, the investigation of differences in confessions between two groups of persons: accused of committing a criminal offense by one person and accused of committing a criminal offense by a group of persons, identification of the connection between the prosecution methods and the trial duration with pre-trial investigation stages where the accused tend to give confessional testimony.

4. Statement of the task

Survival analysis is used to identify non-obvious relationships between the elements of the process of suspect's guilt recognition in the commission of a criminal offense

[14]. Applied investigations are carried out on the basis of official statistical data about 787 persons accused of committing criminal offences provided by the judicial administration of the District Court. It is formed on the basis of materials sent to the court of criminal proceedings [15]. The dataset contains the following variables:

- *Month 1*, *Day 1*, *Year 1* – month, day and year of information input into the Unified Register of Pre-trial Investigations (URPI);
- *Month 2*, *Day 2*, *Year 2* –month, day and year of the verdict date in the criminal proceedings;
- *time to confess* – trial duration or the end of the observation period (entry into force of the guilty verdict, the closing of the case, stay in the proceedings, etc.);
- *organized crime* – method of prosecution: crime committed by one person; crime committed by a group of persons;
- *censored* – censored observations indicator: the value *complete* is set only for defendants who are definitely known to plead guilty to a criminal offense; all other records are set to the value *censored*.

After completing the investigation, there are a number of accused about whom it is not known whether they have pleaded guilty to committing a crime (the case is transferred to another court body, the suspect is acquitted due to lack of evidence of guilt, the case is pending, etc.). It would be inexpedient to lose the information about them, since most of these accused did not confess to the crime during the investigation period. Such observations are used in the investigation as censored. Survival analysis tools are used to investigate censored (incomplete) data [14].

The survival function determines the probability that the object will "survive" time t:

$$S(t) = P(T > t) \quad (1)$$

The most common method of survival description in the sample is the construction of tables and distributions of “life” times (“survival”), intended for the calculation of the simplest statistics and description of the “survival” time of objects (the defendant does not admit to committing a criminal offense). The range of possible times of critical events occurrence (the defendant's confession to the commission of a criminal offense) is divided into 12 intervals. Table No. 1 represents the following attributes of the survival table:

- Number Entering – the number of objects who were "alive" (accused who did not confess to committing a criminal offense) at the beginning of the investigated time interval.
- Number Withdrawn – the number of objects censored at each interval (removed from observation, label *censored*).
- Exposed – the number of objects that were “alive” at the beginning of the investigated time interval, minus half of the number of removed objects.
- Number Dying – the number of objects who “died” (accused that confessed to committing a crime) in the given interval (label *complete*).
- Proporth Dead – the ratio of the number of objects who ”died” in the current interval to the number of objects investigated in this interval.
- Proporth Surviving (proportion of objects who “survived”): unit minus the proportion of “survived” (defendants who pleaded guilty to a criminal offense).
- Cump. Prop. Surviving – the cumulative proportion of “survivors” (defendants who have pleaded not guilty to a criminal offense), or survival function. This is the probability that the subject will “survive” (the defendant pleads not guilty to

the crime) at the current interval. It is equal to the product of the shares of objects that "survived" (accused who did not plead guilty to committing a criminal offense) over all previous intervals.

- Problty Density – the density of "death" probability of (the defendant admitting guilt in committing a criminal offense) in the given interval: the survival function in the next interval is subtracted from the survival function in the given interval and divided by the length of the interval.

Kaplan-Meier estimates. One of the tasks in survival analysis is to estimate the survival function, that is, the probability that the object "will live" for a certain time after the occurrence of a certain event (completion of the trial). For censored observations, the survival function can be estimated directly without the lifetimes table application.

For chronological events, the following estimation of the survival function takes place:

$$S(t) = \prod \left(\frac{n-j}{n-j+1} \right)^{\delta(j)}, \tag{2}$$

where $S(t)$ is the estimation of survival function, n is the total number of events (sample volume), j is the ordinal (chronological) number of the separate event, $\delta(j) = 1$, if the j-th event means failure ("death") and $\delta(j) = 0$, if the j-th event means the loss of observation (censoring indicator), $\prod$ is the product of all observations j completed up to moment t.

Another popular tool in survival analysis is the exponential model. This is a parametric model assuming the data compliance with a certain distribution. The survival function of the exponential model is as follows:

$$S(t) = \exp(-\frac{1}{\lambda}). \tag{3}$$

It is more difficult to obtain the estimation of the instantaneous risk function, which is the probability of a "fatal outcome" (the accused pleads guilty to a criminal offense) in a short period of time, provided that the object has been "alive" (did not confess) at the beginning of the investigated period. This is an important feature of the event development forecast. Cox proportional hazards model is used for direct estimation of the instantaneous risk function. The investigation is the determination of the fact of individuals' variables connection with the observed lifetimes.

The model of proportional intensities, or Cox proportional hazards, is the most general regression model assuming that the intensity function is as follows:

$$h(t) = h_0(t)\ y(z_1, ..., z_m). \tag{4}$$

The multiplier $h_0(t)$ is the basic intensity function.

The model can be parameterized, for example, in the following form:

$$h[(t),(z_1, z_2, ..., z_m)] = h_0(t) e^{b_1 z_1 + ... + b_m z_m}. \tag{5}$$

The product of two functions and each of them depends on its set of variables is in the right part of the formula. The intensity function $h_0(t)$ can be considered as the intensity function when all covariates are equal to zero. It does not depend on the variable

z (covariate). The second factor depends on the variable z_0, which possibly depends on t.

5. Analysis of numerical results

The table of lifetimes (Table 1) represents the results of the simplest statistics calculation and the description of the "survival" times of objects. The range of possible times of critical events occurrence (the defendant's confession to committing a crime) is divided into 12 intervals.

Table 1. Lifetime Table (fragment 1)

Interval	Log-Likelihood for data: -947.999									
	Interval Start	Mid-Point	Number Entering	Number Withdrawn	Number Exposed	Number Dying	Number Dead	Proportion Surviving	Cum. Prop Surviving
Intno.1	0.00	113.73	787	10	782.00	453	0.58	0.42	1.0000
Intno.2	227.46	341.182	324	19	314.50	146	0.46	0.54	0.4207
Intno.3	454.91	568.64	159	20	149.00	64	0.43	0.57	0.2254
Intno.4	682.36	796.09	75	0	75.00	32	0.43	0.57	0.1286
Intno.5	909.82	1023.55	43	5	40.50	25	0.62	0.38	0.0738
Intno.6	1137.27	1251.00	13	1	12.50	4	0.32	0.68	0.0282
Intno.7	1364.73	1478.46	8	0	8.00	1	0.13	0.88	0.0192
Intno.8	1592.18	1705.91	7	0	7.00	1	0.14	0.86	0.0168
Intno.9	1819.64	1933.36	6	0	6.00	4	0.67	0.33	0.0144
Intno.10	2047.09	2160.82	2	0	2.00	0	0.25	0.75	0.0048
Intno.11	2274.55	2388.27	2	1	1.50	0	0.33	0.67	0.0036
Intno.12	2502.00		1	0	1.00	1	0.50	0.50	0.0024

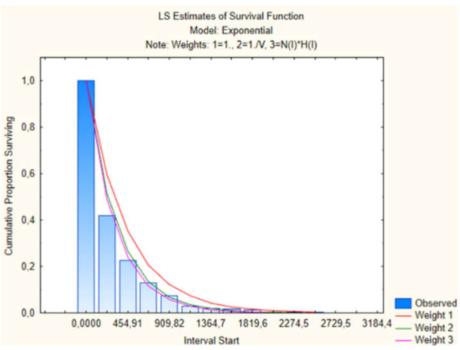
In order to match the data to the family of distributions that best fits the data, the model with exponential distribution is considered. The agreement scores obtained using χ^2 tests are presented in Table 2.

Table 2. Estimation of the Exponential Model parameters

Estimate Method	Parameter Estimates, Model: Exponential Note: Weights: 1=1., 2=1,*N*, 3=N(I)*H(I)						
	Lambda	Variance Lambda	Std.Err. Lambda	Log. Likelhd.	Chi-Sqr.	df	p
Weight1	0.002301	0.000000	0.000351	-1005.01	114.03	10	0.00
Weight2	0.002929	0.000000	0.000104	-971.23	46.46	10	0.00
Weight3	0.003146	0.000000	0.000108	-967.99	39.99	10	0.00

It is evident from Table 2 that the obtained results are significant ($p < 0{,}001$), and all fitting methods give the exponential distribution of satisfactory agreement: $\chi^2(10) > 39$. The plot of the survival function shown in Fig. 1, confirms the correctness of the obtained results. The abscissa shows the duration of the investigation (days). For all three sets of parameters (Weight 1, Weight 2, and Weight 3), satisfactory agreement with the data is observed. The exponential distribution with these data sets satisfactorily describes the observed lifetimes. It can be concluded that at the initial stages of the investigation, the accused are the least prone to plead guilty to a criminal offense (the probability of confession ("death") is minimal). However, it increases sharply during the first six months and reaches its maximum after three years of the trial.

In order to analyze the process of making a decision by the accused to plead guilty to a criminal offense, the plot of the instantaneous risk function (failure analysis) is constructed. This function calculates the probability that the accused will plead guilty to a criminal offense in the next observation interval (during the duration of the investigation), given that he has not confessed at the beginning of the observation interval. The plot of the risk function shown in Fig. 2, clearly demonstrates that at the beginning of the investigated period, the risk of "death" (the accused pleads guilty to a criminal offense) is high; over the next 2 years, it declines.



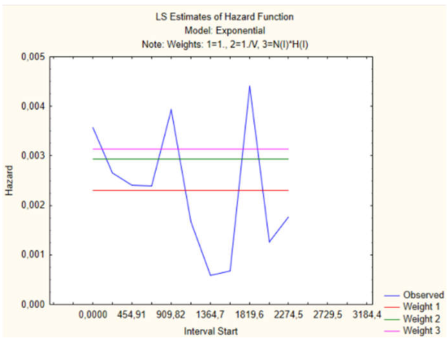


Figure 1. Estimations of the survival function

Figure. 2. Risk function plot

In the third year of the duration of the investigation, the probability that the accused will plead guilty to a criminal offense increases to a maximum value and decreases to a minimum for the next more than 1.5 years. The lowest probability that the accused will plead guilty to a criminal offense is observed in the 4th year of the investigation and reaches its peak again in the 5th year. After that, it drops again almost to its minimum value and slightly increases at the end of the investigation (the duration of the investigation). It is the risk function that is used for predictive purposes. This makes it possible for investigative bodies of pre-trial investigation and the prosecutor's office to assess the chances of obtaining a confession at certain stages (time periods) of the trial.

The risk function plot, which fluctuates continuously throughout the observation period, shows the dependence and riskiness of suspects who change their readings. The obtained risk estimates have small errors (Str. Err. Haz. Rate), therefore, they can be considered acceptable (Table 3).

Table 3. Lifetime Table (fragment 2)

Interval	Log-Linkelyhood for data: –947.999						
	Probity Density	Hazard Rate	Std. Err. Cum.Surv	Std. Er.r Prob.Den	Std. Err. Haz.Rate	Median Life Exp	Std. Err. Life Exp
Intno.1	0.002547	0.003585	0.000000	0.000078	0.000154	196.3239	7.02053
Intno.2	0.000859	0.002658	0.017654	0.000063	0.000210	262.8098	27.86643
Intno.3	0.000426	0.002405	0.015147	0.000049	0.000289	293.3076	38.27808
Intno.4	0.000241	0.002385	0.012579	0.000040	0.000406	274.5852	37.10580
Intno.5	0.000200	0.003925	0.010293	0.000037	0.000703	184.2382	28.95024
Intno.6	0.000040	0.001675	0.006872	0.000019	0.000822	689.0535	94.60862
Intno.7	0.000011	0.000586	0.005974	0.000010	0.000585	568.6364	80.41733
Intno.8	0.000011	0.000676	0.005689	0.000010	0.000674	369.6136	75.22352
Intno.9	0.000042	0.004396	0.005358	0.000020	0.001904	170.5909	69.64345
Intno.10	0.000005	0.001256	0.003295	0.000007	0.001758	454.9091	0.00000
Intno.11	0.000005	0.001759	0.002875	0.000007	0.002437	227.4545	0.00000
Intno.12			0.002364				

The median life expectancy is the time points at which the survival function is equal to 0.5. For example, it follows from the first line of Table 3 that the accused with a probability of 0.5 does not plead guilty to committing a criminal offense during the first 196 days from the moment of information input into the Unified Register of Pre-trial Investigations. If the accused "survived" (did not confess) during the first interval (196 days), then the median time of his "life" would be 262. This means that the accused does not plead guilty for the next 262 days, and so on.

The calculated estimations of the survival function (the probability that the accused will not plead guilty to a criminal offense) at a certain time after the end of the investigation (the end of the duration of the investigation) are shown in Table 4. The obtained results can provide investigative bodies, prosecutor's offices and courts with information about the probable possibility of making a decision for the accused to give confessional testimony after making a procedural decision in the proceedings (Table 4).

Table 4. Estimations of the survival function (Kaplan-Meier model)

	Kaplan-Meier (Product-limit) analysis. Note: Censored cases are marked with +						
Case Num.	Time	Cumulat. Survival	Standard Error	Case Number	Time	Cumulat. Survival	Standard Error
743	7.000	0.9987	0.0013	30+	575		
669	14.000	0.9975	0.0018	126	579	0.1659	0.0138
780	14.000	0.9949	0.0025	81	583	0.1629	0.0137
91+	561.000			112+	586		
85	563.000	0.1707	0.0139	1	2034	0.0047	0.0033
129+	563.000			768+	2458		
72	571.000	0.16776	0.0138	621	2502	0.0000	0.0000

The standard error of the survival function is quite small, although larger than the error for the lifetime tables. The obtained results are correct. From Table 4 it is obvious, for example, that the probability that the accused will not plead guilty to committing a criminal offense for more than 15 days is 0.99. The probability that he will not confess for more than 563 days is 0.17. The first column of the table displays the number of observations for which a certain event (confession) has occurred at a given point in time. The "+" sign means that the observation is censored (the criminal case is closed or it is pending).

The plot of the survival function obtained by the Kaplan-Meier method is shown in Fig. 3. It confirms the obtained results: the probability that the accused will not admit guilt in committing a criminal offense is inversely proportional to the duration of the investigation.

The differences between the decision to plead guilty to the commission of a criminal offense for two groups of defendants are studied: in the commission of a criminal offense by one person and in the commission of a criminal offense by a group of persons. Table 5 represents the estimations of the logarithmic rank test for comparison of the confession process in groups. This is the non-parametric test for incomplete observations.

Table 5. The results of the log-rank test (fragment)

	Long-Rank Test WW = 22.404 Sum = 722.375 Var = 30.736 Test statistic = 4.041071 p = 0.00005				
Survival Time	Group	Score	Survival Time	Group	Score
516.00	0.0000	-0.63041	527.00	0.0000	-0.65314
516.00+	0.0000	-1.63041	530.00+	0.0000	-1.65314
518.00	0.0000	-0.63787	535.00	0.0000	-0.66095

	Long-Rank Test WW = 22.404 Sum = 722.375 Var = 30.736 Test statistic = 4.041071 p = 0.00005				
Survival Time	Group	Score	Survival Time	Group	Score
523.00+	0.0000	-1.63787	535+.00	0.0000	-1.66095
526.00	0.0000	-0.64545	537.00	0.0000	-0.66889
526.00+	0.0000	-1.64545	537.00+	0.0000	-1.66889

The logarithmic rank test is a popular test for testing the null hypothesis of no difference in survival between independent groups. The test compares the total "survival" experience between the groups and can be considered as the test of the survival curves identity. Due to the Kaplan-Meier method, the curve estimations for each of the selected groups are obtained. Statistical comparison of survival curves is carried out by means of the logarithmic rank test, which uses the χ^2 test for the null hypothesis. The degree of freedom for this test is $k - 1$, where k is the number of comparison groups. In our investigation $k = 2$, therefore the test degree of freedom is $df = 1$. From the χ^2 distribution table for $p < 0.01$, we get that the difference between the groups is statistically significant: $\chi^2_{емп} < \chi^2_{теор}$. There is no statistically significant evidence that the process by which defendants decide to plead guilty to a criminal offense has significant differences for selected groups of defendants.

It can be seen from Fig. 4 that the same results are confirmed by the diagram of differences between groups. It can be concluded that no significant differences are found in the decision of the accused to plead guilty to the commission of a criminal offense by one person (group 0) and the crime committed by a group of persons (group 1).

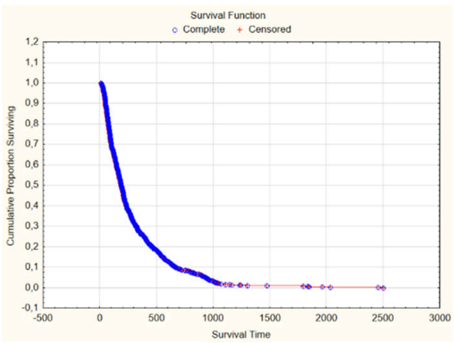


Figure 3. The plot of the survival function

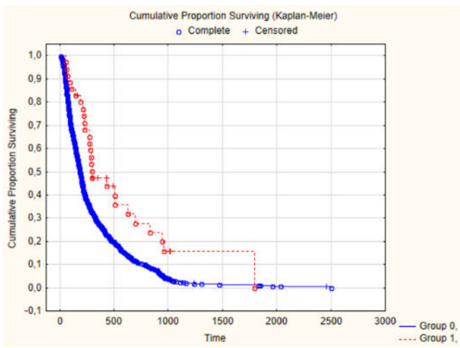


Figure 4. Differences between groups

In order to determine the probable dependence of the method of prosecution and the stage of the pre-trial investigation at which the accused pleads guilty, Cox proportional risks regression model is constructed (Table 6).

Table 6. Parameter estimations of the Cox proportional risks model

	Dependent Variable: Survival times in days Censoring var.: censored Chi² = 790.663 df = 2 p = 0.0000					
N=800	Beta	Standard Error	t-value	Wald Statist	p	Risk ratio
time to confess	-1.53745	0.062600	-24.5600	603.1920	0.000	0.215
organized crime	-0.31142	0.173520	-0.7947	0.0710	0.071	0.732

The value of χ^2 statistics for this model is highly significant ($p < 0.001$). At least one of the independent variables of the model is significant. Approximate estimates of the *t*-value of the regression model parameters can be considered statistically significant only for the variable *time to confess*. Close to zero parametric statistical measure of Wald (*Wald Statist*.) for the variable *organized crime* confirms its insignificance for the constructed model. The negative *t*-value indicates the change in the direction of the effect, unrelated to the significance of the difference between groups.

Therefore, *time to confess* (the duration of the investigation) is the most important predictor for the instantaneous risk function. For the investigated sample, the stage of pre-trial investigation, where the accused make the decision to plead guilty, significantly depends on the trial length, and does not depend on the prosecution method.

The *time to confess* is the most important predictor for the instantaneous risk function. The regressors in the model are independent of each other (correlation coefficient -0.015). The obtained simulation results are correct.

The plot of the survival function for the case when all independent variables are equal to their average value is presented in Fig. 5.

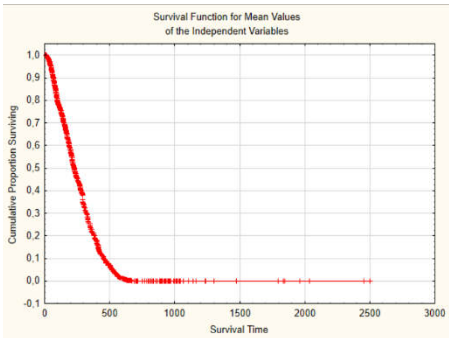


Figure 5. The survival function for mean values of the independent variables

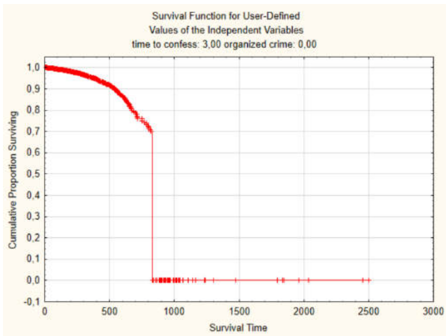


Figure 6. The survival function for confess = 3, organized crime = 1

The plot of survival functions for different values of regressors (*time to confess* – value in years; *organized crime*: 0 – a crime committed by one person, 1 – a crime committed by a group of persons) presented in Fig. 6-8 confirm the previously obtained results: the stage of the pre-trial investigation, at which the accused will decide to plead guilty, depends on the length of the trial and does not depend on the method of prosecution.

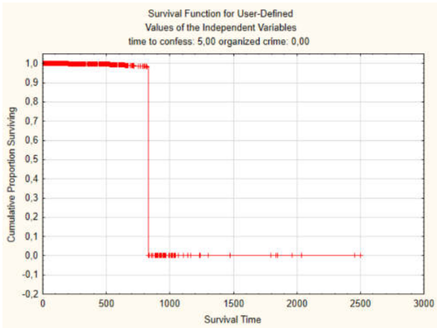


Figure 7. The survival function for time to confess = 5, organized crime = 0

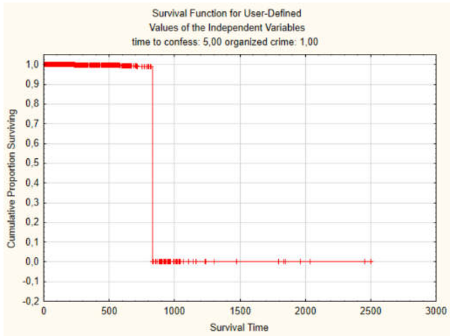


Figure 8. The survival function for time to confess = 5, organized crime = 1

5. Conclusions

The probability of the accused confessing to a criminal offense at each of the stages (time periods) of the trial is calculated. The chances of not admitting guilt in committing a criminal offense by the accused for a certain time after the end of the trial are determined. It is proved that there are no differences in confessions between two groups of defendants: in the commission of a criminal offense by one person and in a crime committed by a group of persons. The chances of obtaining confessional evidence after the end of the criminal trial are calculated. The probability of guilty pleas by the accused in a short period of time is determined. It is established that the stage of the pre-trial investigation, at which the accused is more prone to plead guilty, depends significantly on the duration of the trial and does not depend on the method of prosecution. The obtained results can provide relevant information to the justice authorities regarding the optimization of investigative tactics to obtain evidence of confessions, particularly, to assess the chances of obtaining confessions from the accused at certain stages of the trial or after the completion of the investigation. This will reduce the risks of errors in criminal investigations and increase the level of public safety in general. The next stage of our investigations is the study of the risks and negative effects of admitting guilt in the commission of criminal offenses by minors.

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