The Risks Assessment of Delivery Failures for Application-to-Person SMS Market

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Abstract

Despite the widespread development of communication technologies, SMS messages remains widely used by mobile subscribers, mobile operators, and enterprises. Nowadays, Application-to-Person SMS is actively developing to deliver content of different kind to mobile phone from enterprises, banks, mobile operators, and also valid for Mobile Internet of Things. Due to the action of various random factors, SMS messages may not be delivered, which can lead to mobile subscribers dissatisfaction and reduce the level of trust in the communication service operator. This paper concentrates on the analysis and assessment of delivery failures risks for application-to-person SMS market. The main attention is paid to the mathematical model building for statistical data on messages transmitting by communication service provider. The cumulative probabilities of successful messages delivery are described using exponential and hyperbolic models. The unknown coefficients of models are estimated based on iterative procedure. Model correction during iteration is possible due to the optimization paraboloid usage. The proposed methodology gives the possibility to create online decision-making platform with predictive capability for fast and accurate estimation of delivery failures risk.

Keywords

Risks assessment, Short Message Service, SMS completion failure ratio, mathematical model building, exponential model, hyperbolic model

1. Introduction

The short message/messaging service (SMS) is in use for almost 30 years now. It has been first sent on December 3, 1992, using a personal computer and it was addressed to a mobile phone [1]. Since then, SMS has become one of the most used communication channels worldwide. It became possible due to simplicity, availability and accessibility of the SMS. Hence the age, SMS remains widely used by mobile subscribers, mobile operators, and enterprises. Forecasts show that only Application-to-Person (A2P) SMS market was valued at 64.42 Billion USD in 2021 and it is expected to reach 84.18 Billion USD by 2029, exhibiting the compound annual growth rate of 3.43% during the forecast period. According to the GSMA Mobile Economy 2020

CITRisk'2022: 3rd International Workshop on Computational & Information Technologies for Risk-Informed Systems, January 12, 2023, Neubiberg, Germany
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research, there were over 6.1 billion unique mobile subscribers in 2021, with smartphones accounting for 60% of connections [2].

Range of SMS use cases continues to expand. It started with:

1. Point-to-Point (P2P) SMS: providing means of sending messages to and from mobile phones.
2. Application-to-Person (A2P) SMS: used to deliver content of different kind to mobile phone from enterprises, banks, mobile operators, and others, and also valid for Mobile Internet of Things (MIoT).
3. Technical enabler: Over The Air (OTA) messaging used for Universal Mobile Telecommunications System (UMTS) Subscriber Identity Module provisioning, Internet Protocol (IP) session wake-up [3].

Another important function of SMS is being a part of emergency communications. Short Message Service or SMS messages can be sent to a mobile terminal without special options needing to be set on the handset. SMS is widely known and accepted, and messages can contain detailed instructions for citizens on required actions to take. Under normal conditions, delivery can be almost instantaneous, but a large number of messages require considerable time.

Since the mobile terminal acknowledges successful reception of the SMS, the retry mechanism guarantees a very high rate of successful delivery. Severe network congestion may lead to a delayed delivery. SMS in itself is not location specific. However, there are technical means to detect where mobile handsets are located, but not necessarily in a timely manner. Active probing generates a lot of traffic on the signaling channels and passive probing requires expensive equipment to probe each Radio Access Network (RAN) node [4].

2. Related works

The analysis of literature in the field of SMS-based communication channels showed that sufficient attention is paid to scientific research of these channels effectiveness and possibilities of such technologies utilization in various branches of human society.

The SMS is a very cheap, at the same time highly reliable way to use the communication channel, and can be used on all mobile terminals [5]. Almost 100% of the population worldwide uses the mobile phone and is able to send and receive short text messages. Benefits of using short text messages encourages their adoption in business and industry.

When using SMS messages, information security methods can also be applied [6]. The security of messages and the use of additional encryption methods make it possible and promising to use SMS for banking purposes [7]. Moreover, additional SMS sending can improve the quality of steganography when sending encrypted voice messages [8].

The branches of SMS utilization are different. Paper [9] presents a web-based SMS management system whose main function is to enable non-technical users to perform SMS study reconfiguration. The presented system has been tested for the purposes of medicine and health monitoring, as well as ensuring child development monitoring.

Paper [10] concentrates on SMS-based system as supporting tool of global position system for tracking a moving target. Using SMS for such purpose provides suitable response time and acceptable accuracy for location tracking.

The possibilities of SMS usage for user authentication throughout the internet are discussed in [11]. The authors analyzed the scenario for successful information delivery, techniques of encryption to eliminate the events of user account hijacking.

Due to the action of various random factors, SMS messages may not be delivered, which may lead to mobile subscribers dissatisfaction and reduce the level of trust in the communication service operator [12]. Various methods to improve the quality of SMS delivery can be applied. Paper [13] deals with the analysis of SMS behaviors and estimation of efficiency in form of delivery failures. To reduce the delivery delay, authors proposed to implement timeout timer. Paper [14] discusses the robust SMS platform based sliding window and technique of load balancing. The proposed methodology, which provides high efficiency, is used for aviation information service application system with ability to meet strong requirements for aviation safety providing [15]. Paper [16] presents the method for extending the coverage area for SMS communication based on Long Range (LoRa) networks.

To analyze the efficiency of SMS transmitting, the statistical methods are usually used. Paper [17] focuses on mathematical background for cost analysis while SMS retransmission using real data example. Another example of statistical analysis of real data on mobile banking services is considered in [18].

To carry out statistical analysis of data on SMS delivery can be used methods and technique from related fields of study, for example spline-approximation technique that discussed in [19], methods of diagnostic variable model building considered that considered in [20], sequential methods of diagnostic variable estimation proposed in [21] and others.

This paper concentrates on the analysis and assessment of delivery failures risks for application-to-person SMS market. The main attention is paid to the mathematical model building to estimate the SMS completion failure ratio. The initial information for mathematical model building is statistical reports on messages transmitting by communication service provider.

3. Materials and methods

3.1. Key parameters for defining reliability of SMS service

Provided the wide range of SMS use cases and it being essential part of GSM suite, quality of service is regulated by standard set by The European Telecommunication Standard Institute (ETSI) in its latest technical specification ETSI TS 102 250-2 v.2.7.1 (2019-11) “Speech and multimedia Transmission Quality (STQ); QoS aspects for popular services in mobile networks; Part 2: Definition of Quality of Service parameters and their computation”. Parameter overview chart with trigger points is shown in Figure 1.

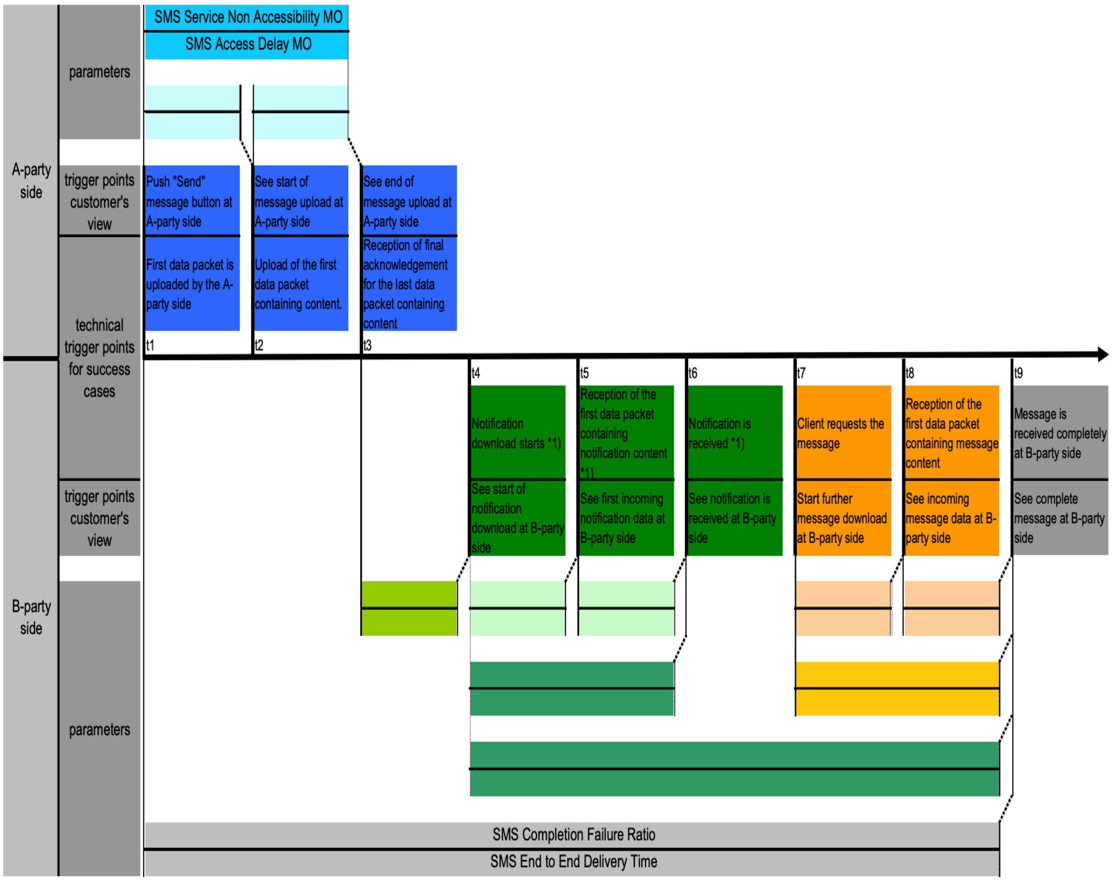


Figure 1: SMS parameter overview with trigger points

The following set of parameters for evaluation of quality of service is defined [22]:

1. SMS Service Non-Accessibility [%] – denotes the probability that the end-user cannot access the short message service when requested while it is offered by display of the network indicator on the User Equipment (UE).
2. SMS Access Delay [s] – denotes the time period between sending a short message to the network and receiving a send confirmation from the network at the originating side.
3. SMS Completion Failure Ratio [%] – corresponds to the ratio of unsuccessfully received and sent messages from one UE to another UE, excluding duplicate received and corrupted messages.
4. SMS End-to-End Delivery Time [s] – corresponds to the time period between sending a short message to the network and receiving the very same short message at another UE.
5. SMS Receive Confirmation Failure Ratio [%] – denotes the probability that the receive confirmation for a sent attempt is not received by the originating UE although requested.
6. SMS Receive Confirmation Time [s] – corresponds to the time period between sending a short message to the network and receiving the receive confirmation for this message from the network.

7. SMS Consumed Confirmation Failure Ratio [%] – denotes the probability that the consumed confirmation for a sent attempt is not received by the originating UE although requested.

8. SMS Consumed Confirmation Time [s] – corresponds to the time period between sending a short message to the network and receiving the consumed confirmation from the network.

As P2P SMS usage declines over past decade [23], and usage of A2P SMS, MIoT and OTA SMS is expanding such parameters as SMS Completion Failure Ratio, SMS End-to-End Delivery Time, SMS Receive Confirmation Time become the key parameters as it affect the mobile terminated (MT) SMS.

The transaction flow for MT SMS scenario shown in Figure 2.

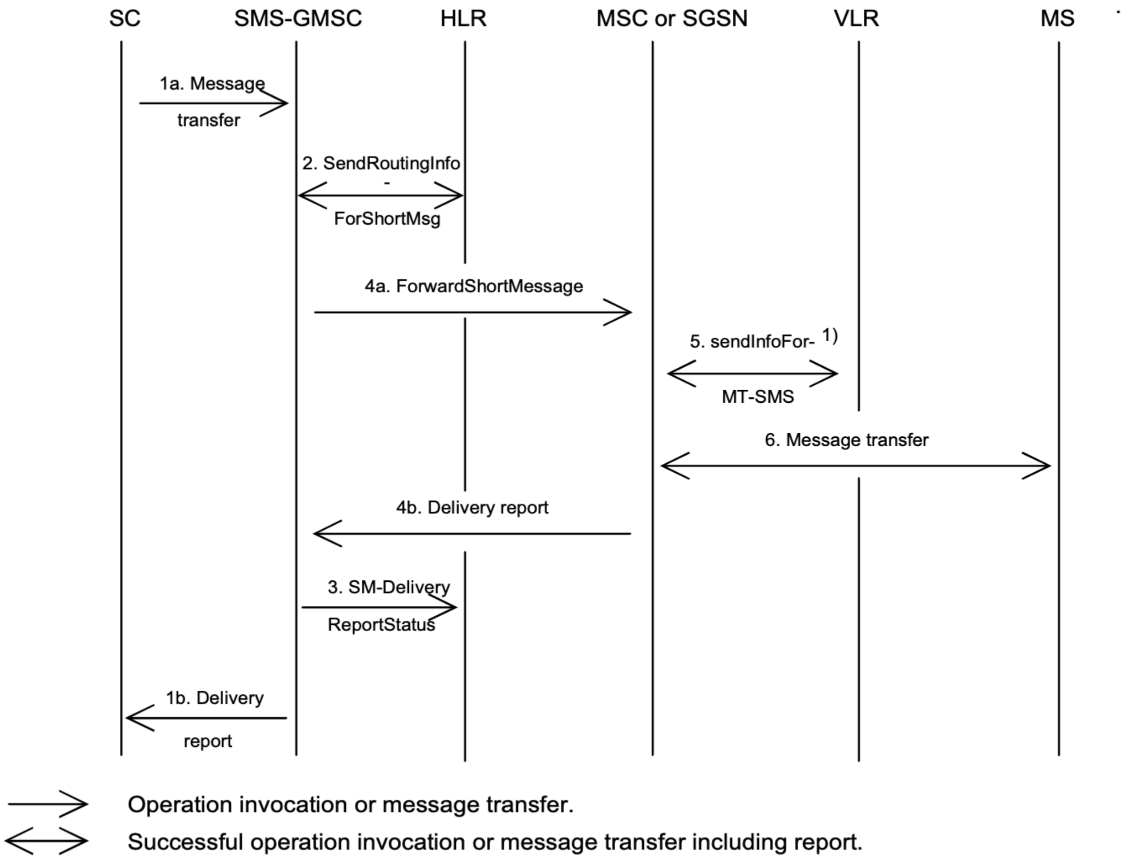


Figure 2: MT SMS transaction flow

SMS Completion Failure Ratio is calculated by following equation [22]:

$$\text{SMS Complition Failure}[\%] = \frac{\text{unsuccessfully received SMS}}{\text{all SMS service attempts}} \times 100 .$$

SMS End-to-End Delivery Time is calculated by following equation:

$$\text{SMS End-to-End Delivery Time [s]} = t_{B,receive} - t_{A,send} \text{ [s]}.$$

SMS Receive Confirmation Time is calculated by following equation:

$$\text{SMS Receive Confirmation Time}\,[\text{s}] = t_{B,receiveconfirmation} - t_{A,send} \ \ [\text{s}].$$

These parameters can be affected on different stages of message delivery: congestion in the SMS system (between SMS originator and Mobile operator network), congestion in signaling links in mobile operator's network or in the interworking connections (connection between mobile operators), service non-availability in certain geographical areas.

The risk of delivery failures for A2P SMS Market can be considered as SMS Completion Failure Ratio. Let this risk is q , then $p = 1 - q$ is the probability of correct delivery of SMS.

3.2. Mathematical model building for SMS delivery parameter

Consider the real data example of SMS delivery performance.

Table 1 presents statistical data showing SMS MT sent across all operators in country A in the period of time 15/10/22-31/10/22 by one of Communication Platform As A Service (CPAAS) providers.

Table 1

SMS MT delivery statistics between 15/10/2022 and 31/10/2022

SMS MT Delivery parameter	Number of SMS MT
Total	2492766
Delivered	2196792
Expired	159584
Undeliverable	136390
Delivered within 10s	1811373
Delivered within 30s	248302
Delivered within 1m	36723
Delivered within 5m	55041
Delivered within 15m	11394
Delivered within 30m	6490
Delivered within 1h	7329
Delivered within 3h	6616
Delivered within 6h	3450
Delivered within 12h	2931
Delivered within 24h	3870
Delivered within 48h	3273

Data from Table 1 show that in this case 82.46% of all delivered SMS MT are delivered within 10 seconds, which is acceptable value.

Observed data can be considered as time series with discrete time and measurements in time moment $t = \{10, 30, 60, 300, 900, 1800, 3600, 10800, 21600, 43200, 86400, 172800\}$ [s]. To build the mathematical model for such time series can be used general approximation techniques, for example described in [24]. The quantity of delivered messages decreases over time. The range of change for this quantity is significant.

To represent the data better, logarithmic scale for quantity and time is more preferable for visual analysis. In addition, the natural logarithms for cumulative quantity of delivered SMS can also be used. To estimate the risk of delivery failures, the current statistical probabilities of successful delivery p_i and corresponding cumulative probabilities $p_{\Sigma i}$ are calculated.

Figure 3 shows the initial dependencies for observed data presented in Table 1.

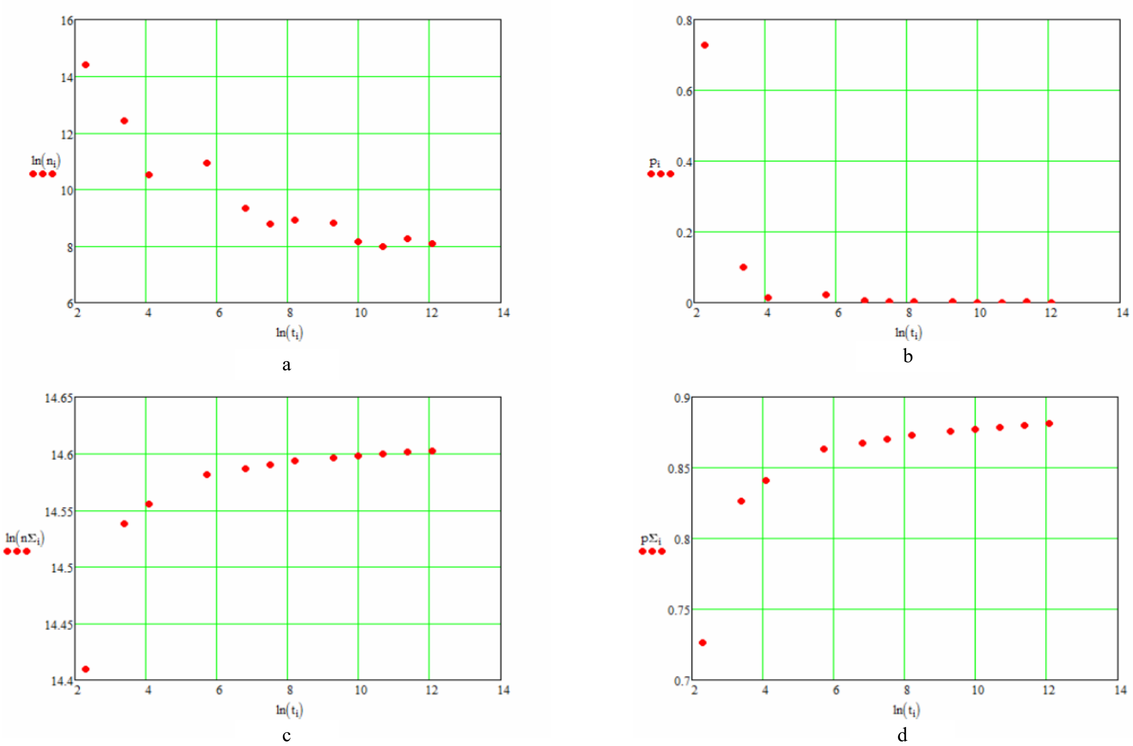


Figure 3: Observed time series: a – dependence of delivered messages quantity on time; b – dependence of statistical probabilities of successful delivery on time; c – dependence of cumulative quantity of delivered messages on time; d – dependence of cumulative probabilities of successful delivery on time

Visual analysis of dependencies presented in Figure 3 makes it possible to conclude that cumulative curves are more suitable for risk assesment of delivery failures.

Consider two alternative models for risk assessment.

1. Exponential model.

This model is determined according to following equation:

$$f(t) = a - ae^{-bt}, \tag{1}$$

where a and b are model coefficients need to be estimated.

It should be pointed out that in case of cumulative probabilities data analysis the estimate of model coefficient a is suitable for assessing the probability of correct delivery of SMS. So the risk of delivery failures can be found as $q = 1 - a$.

The general approach to estimate the model coefficient is usage of ordinary least squares method after making assumption about normal distribution of errors. In this case, it is necessary to solve the system of equation

$$\begin{cases} \sum_{i=1}^{N} f_i (e^{-bt_i} - 1) - a \sum_{i=1}^{N} (e^{-bt_i} - 1)^2 = 0, \\ \sum_{i=1}^{N} f_i t_i e^{-bt_i} - a \sum_{i=1}^{N} t_i e^{-bt_i} + a \sum_{i=1}^{N} t_i e^{-2bt_i} = 0. \end{cases}$$

The solution of such system of equation is complicated problem.

Consider alternative approach. At the first iteration, we can calculate the unknown coefficients making assumption that exponential curve (1) contains first and last sample of initial dataset. In this case, it is necessary to solve the system of equation

$$\begin{cases} f_1 = a(1 - e^{-bt_1}), \\ f_N = a(1 - e^{-bt_N}). \end{cases}$$

After mathematical simplification, we can get

$$a = \frac{f_1}{1 - e^{-bt_1}}.$$

The model coefficient b can be found as non-zero solution of equation

$$\frac{f_1}{f_N} - 1 + e^{-bt_1} - \frac{f_1}{f_N} e^{-bt_N} = 0.$$

To solve this equation, one of the numerical method can be used.

The second iteration is associated with minimizing the standard error of the model. For this purpose, optimization paraboloid can be implemented. The general methodology of mentioned optimization is discussed in [24].

To estimate the risk of delivery failures using complete statistical data, we need to analyze data observed within two days. The using of exponential model (1) building technique gives the ability to construct online decision-making platform with predictive capability for fast estimation of delivery failures risk. For example, we can measure the data within 5 minutes duration and for corresponding data estimate the model coefficients with subsequent recalculation of one of these coefficients into the risks of delivery failures. The flowchart of corresponding method is shown in Figure 4.

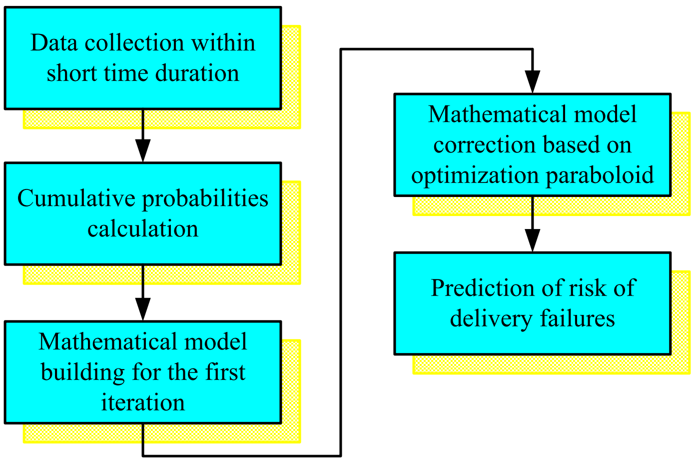


Figure 4: The flowchart of risk assessment of delivery failures

Consider the example of model building for data shown in figure 3d. The first iteration gives the following estimates of model coefficients: $a = 0.881$ and $b = 0.756$. The mathematical model of cumulative probabilities will be

$$p_{\Sigma}(\ln t) = 0.881 - 0.881 e^{-0.756 \ln t}. \tag{2}$$

To correct the mathematical model, we considered 25 options of model coefficients (five possible values of each coefficient) and calculated standard deviations. The results of computation are presented in Table 2.

Table 2

The results of standard deviations computation

S(*a*, *b*)	*b* = 0.656	*b* = 0.706	*b* = 0.756	*b* = 0.806	*b* = 0.856
a = 0.861	0.03308	0.02535	0.0197	0.01639	0.01551
a = 0.871	0.02489	0.0164	0.009999	0.007296	0.009344
a = 0.881	0.01918	0.01099	0.006288	0.008203	0.01285
a = 0.891	0.01843	0.01409	0.01438	0.01763	0.02177
a = 0.901	0.02312	0.02241	0.02454	0.028	0.03183

The data from Table 2 was approximated using paraboloid and ordinary least squares method. The calculation gives the following model of paraboloid:

$$S(a,b) = 26.079 - 55.695a + 30.091a^2 - 4.173b + 0.591b^2 + 3.692ab.$$

The minimum of paraboloid determines the best model coefficients: $a_{\text{opt}} = 0.877$ and $b_{\text{opt}} = 0.791$. Therefore, model (2) after correction takes the optimal form:

$$p_{\Sigma\text{opt}}(\ln t) = 0.877 - 0.877 e^{-0.791 \ln t}. \tag{3}$$

The result of approximation using model (3) is shown in Figure 5.

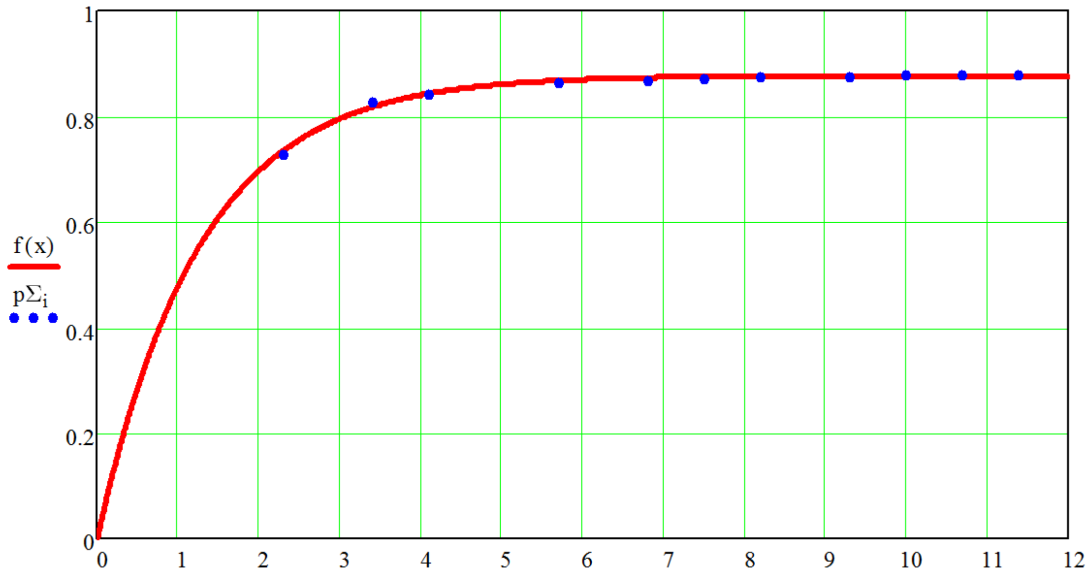


Figure 5: Exponential model for cumulative probabilities of successful delivery

So the risk of delivery failures for model (3) is $q = 1 - a_{\text{opt}} = 0.123$.

2. Hyperbolic model.

This model is determined according to following equation:

$$f(t) = \frac{at}{1 + bt}, \tag{4}$$

where a and b are model coefficients need to be estimated.

To determine the risk of delivery failures, we can analyze cumulative probabilities similar to the model (1). But in this case, the risk of delivery failures can be approximately found as $q \approx 1 - a/b$.

The exact values of model coefficients are solutions of the system of two equations obtained after using ordinary least squares method:

$$\begin{cases} \sum_{i=1}^{N} \frac{f_i t_i}{1 + bt_i} - a \sum_{i=1}^{N} \frac{t_i^{\,2}}{(1 + bt_i)^2} = 0, \\ \sum_{i=1}^{N} \frac{f_i t_i^{\,2}}{(1 + bt_i)^2} - a \sum_{i=1}^{N} \frac{t_i^{\,3}}{(1 + bt_i)^3} = 0. \end{cases}$$

To simplify estimation of model coefficients, we can use approach described for model (1). Therefore, at the first iteration, we assume that hyperbolic curve (4) contains first and last sample of initial dataset. In this case, it is necessary to solve the system of equation

$$\begin{cases} f_1 (1 + bt_1) = at_1, \\ f_N (1 + bt_N) = at_N. \end{cases}$$

After mathematical simplification, we can get

$$a = \frac{f_1 f_N (t_1 - t_N)}{t_1 t_N (f_1 - f_N)} \text{ and } b = \frac{t_1 f_N - t_N f_1}{t_1 t_N (f_1 - f_N)}.$$

At the second iteration, model is corrected using optimization paraboloid.

Consider the example of hyperbolic model building for data shown in figure 3d. After the first iteration, the initial estimates of model coefficients were obtained: $a = 1.455$ and $b = 1.568$. Then the model (4) will be

$$p_{\Sigma}(\ln t) = \frac{1.455 \ln t}{1 + 1.568 \ln t}. \tag{5}$$

At the second iteration, the mathematical model correction was carried out for 25 options of model coefficients (five possible values of each coefficient) based on standard deviations calculation. The results of computation are presented in Table 3.

Table 3

The results of standard deviations computation

S(*a*, *b*)	*b* = 1.508	*b* = 1.538	*b* = 1.568	*b* = 1.598	*b* = 1.628
a = 1.395	0.0277	0.04147	0.05606	0.0706	0.08485
a = 1.425	0.01738	0.02504	0.03828	0.05257	0.06689
a = 1.455	0.02475	0.01682	0.02262	0.03524	0.04922
a = 1.485	0.04123	0.02622	0.01675	0.02044	0.03234
a = 1.515	0.05969	0.04291	0.02779	0.01711	0.01856

The standard deviations can be determined as dependence on model coefficients using ordinary least squares method:

$$S(a,b) = -0.974 - 0.782a + 4.112a^2 + 2.044b + 2.758b^2 - 7.256ab.$$

The minimum of paraboloid determines the best model coefficients: $a_{opt} = 1.444$ and $b_{opt} = 1.529$. Therefore, model (5) after correction takes the optimal form:

$$p_\Sigma(\ln t) = \frac{1.444 \ln t}{1 + 1.529 \ln t}. \quad (6)$$

The result of approximation using model (6) is shown in Figure 6.

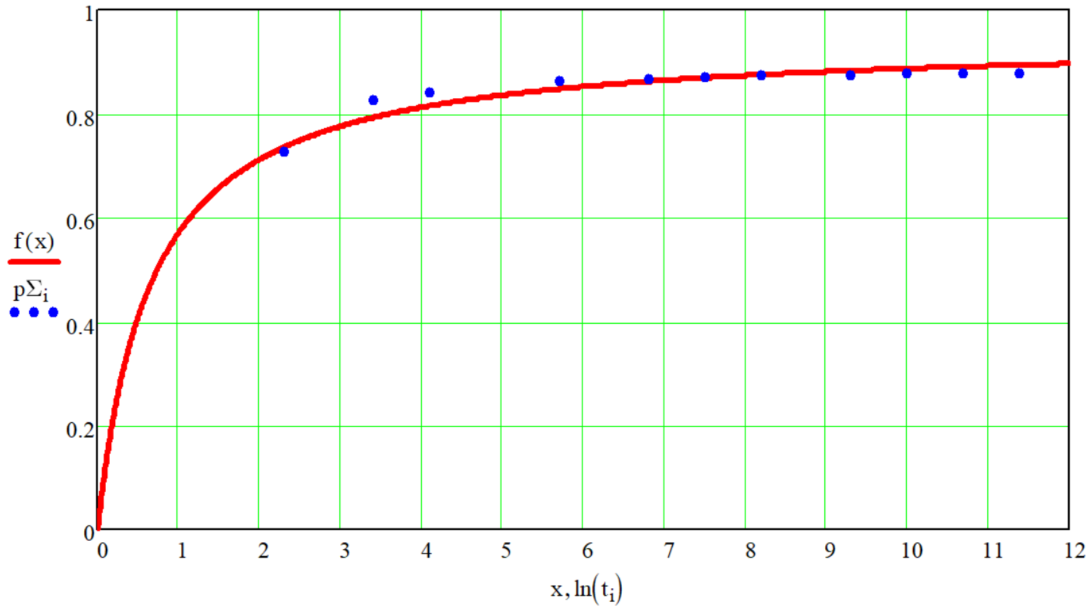


Figure 6: Hyperbolic model for cumulative probabilities of successful delivery

So the risk of delivery failures for model (6) is $q = 0.104$.

4. Results and discussions

This section presents numerical examples of risk assessment for two datasets of SMS MT delivery. The initial data are shown in Table 4.

Table 4

SMS MT delivery statistics between 31/10/22 and 06/11/22 (dataset 1) and between 07/11/22 and 13/11/22 (dataset 2)

SMS MT Delivery parameter	Number of SMS MT (dataset 1)	Cumulative probability	Number of SMS MT (dataset 2)	Cumulative probability
Total	1020320	–	890677	–
Delivered	902546	–	788318	–

Delivered within 10s	740181	0.725	657701	0.738
Delivered within 30s	101664	0.825	73300	0.821
Delivered within 1m	12892	0.838	12076	0.834
Delivered within 5m	22822	0.86	22637	0.86
Delivered within 15m	7920	0.868	6999	0.868
Delivered within 30m	3222	0.871	2562	0.87
Delivered within 1h	3942	0.875	3429	0.874
Delivered within 3h	3152	0.878	3017	0.878
Delivered within 6h	1739	0.88	1427	0.879
Delivered within 12h	1458	0.881	1452	0.881
Delivered within 24h	1930	0.883	1927	0.883
Delivered within 48h	1624	0.885	1791	0.885

Data analysis for the first and second datasets gives possibility to conclude that in both cases real value for delivery failures risk is $q = 0.115$.

Consider the results of risk assessment using proposed methodology and exponential model (1). To make decision about risk value, we use only four values of datasets measured within 5 minutes of observation.

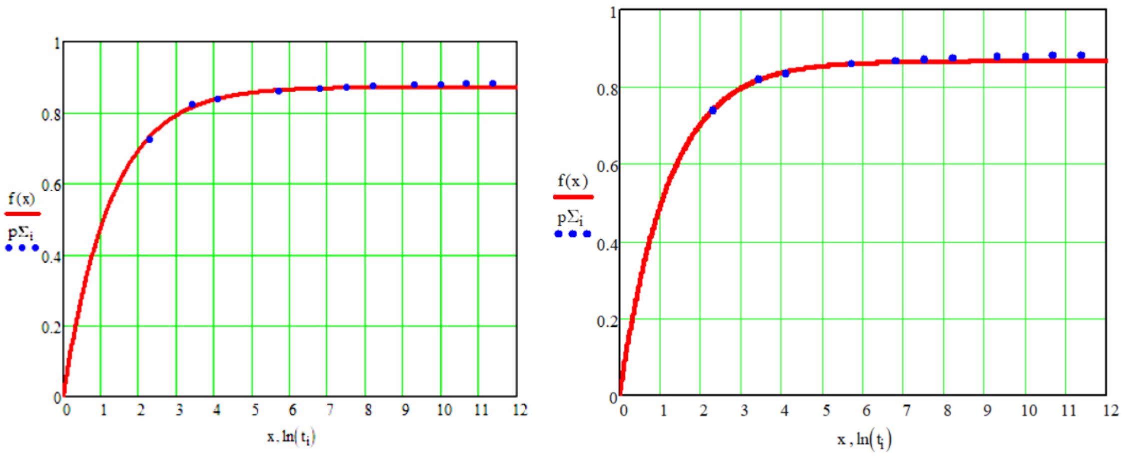
At the first iteration, the following models for two datasets were obtained:

$p_{\Sigma}(\ln t / \text{dataset1}) = 0.870 - 0.870e^{-0.779\ln t}$ and $p_{\Sigma}(\ln t / \text{dataset2}) = 0.867 - 0.867e^{-0.828\ln t}$.

The second iteration gives corrected results:

$p_{\Sigma\text{opt}}(\ln t / \text{dataset1}) = 0.872 - 0.872e^{-0.797\ln t}$ and $p_{\Sigma\text{opt}}(\ln t / \text{dataset2}) = 0.866 - 0.866e^{-0.838\ln t}$.

The results of approximation using exponential model for the first and second datasets are shown in Figure 7.



a b

Figure 7: Exponential model for the first (a) and second (b) datasets

The estimates for failures delivery risk for the first and second datasets are 0.128 and 0.134, respectively. Figure 7 shows good coincidence of data with exponential model and sufficient accuracy of risk assessment in the task of long-term forecasting. At the same time, the exponential model gives slightly increased risk estimates.

Consider the results of risk assessment using proposed methodology and hyperbolic model (4) for data collected within 5 minutes of observation. At the first iteration, the following models for two datasets were obtained:

$$p_{\Sigma}(\ln t/\text{dataset1}) = \frac{1.2\ln t}{1+1.22\ln t} \text{ and } p_{\Sigma}(\ln t/\text{dataset2}) = \frac{1.356\ln t}{1+1.402\ln t}.$$

The second iteration gives corrected models:

$$p_{\Sigma\,\text{opt}}(\ln t/\text{dataset1}) = \frac{1.147\ln t}{1+1.202\ln t} \text{ and } p_{\Sigma\,\text{opt}}(\ln t/\text{dataset2}) = \frac{1.327\ln t}{1+1.392\ln t}.$$

The estimates for failures delivery risk for the first and second datasets are 0.111 and 0.1. The hyperbolic model has sufficient accuracy and gives slightly decreased risk estimates.

To increase the accuracy of risks assessment, it is desirable to organize data collecting with high enough sampling frequency within 5 minutes observation.

5. Conclusion

The SMS remains widely used in human communication, business and industry because of low cost, simplicity of use, adaptability to all mobile phones. Analysis has shown that A2P SMS-based communication market is still growing. Due to the action of various random factors, SMS messages may not be delivered, which can lead to mobile subscribers dissatisfaction and reduce the level of trust in the communication service operator. At the same time, different applications face the problem of increasing the efficiency of SMS transmitting in terms of improvement for SMS completion failure ratio.

Analysis of main parameters for evaluation of quality of service gives possibility to choose the risk of SMS delivery failure as the main efficiency measure having influence of consumers' satisfaction and services costs.

This paper concentrates on the analysis and assessment of delivery failures risks for A2P SMS market. The main attention is paid to the mathematical model building to estimate the SMS completion failure ratio. The initial data for model building are SMS MT delivery statistics. For convenience, these data are converted to the cumulative probabilities of successful delivery.

The cumulative probabilities of successful messages delivery are described using exponential and hyperbolic models. The unknown coefficients of models are estimated based on iterative procedure. At the first iteration, initial values of model coefficients are estimated making assumption about model curve containing two samples of observed dataset. At the second iteration, model is corrected using optimization paraboloid technique. The final models are used to assess the risk of SMS delivery failures.

The proposed methodology gives the possibility to create online decision-making platform with predictive capability for fast and accurate estimation of delivery failures risk.

The future research directions are associated with:

– substantiation of the structure for efficiency support system of SMS communication channel based on risks forecasting of SMS delivery failures;

– costs analysis due to SMS unsuccessful delivery;

– implementation of artificial intelligence method for optimization of SMS communication channel.

References

[1] BBC News, Hppy bthdy txt!, 2002. URL: http://news.bbc.co.uk/2/hi/uk_news/2538083.stm

[2] A2P SMS Market: Technology Trends, Opportunities, Competitive Analysis and Challenges for the manufacturer, 2022. URL: https://www.maximizemarketresearch.com/market-report/global-a2p-sms-market/54244/

[3] SMS Evolution Version 1.02.0, 2020. URL: https://www.gsma.com/newsroom/wp-content/uploads/NG.111-v2.0.pdf

[4] ETSI TS 102 182 V1.5.1 (2020-07), Emergency Communications. Requirements for communications from authorities/organizations to individuals, groups or the general public during emergencies, 2020. URL: https://www.etsi.org/deliver/etsi_ts/102100_102199/102182/01.05.01_60/ts_102182v010501p.pdf

[5] D. van Hassel, L. van der Velden, D. de Bakker, R.Batenburg, "SMS Text Messaging to Measure Working Time: the Design of a Time Use Study Among General Practitioners." BMC Health Services Research, 18, 131, 2018, pp. 1–10. DOI:10.1186/s12913-018-2926-z

[6] S.Gnatyuk, Critical Aviation Information Systems Cybersecurity, Meeting Security Challenges Through Data Analytics and Decision Support, NATO Science for Peace and Security Series, D: Information and Communication Security, 47 (3), 2016, pp.308–316. DOI:10.3233/978-1-61499-716-0-308

[7] M.Kalimoldayev, S.Tynymbayev, S.Gnatyuk, M.Ibraimov, M.Magzom, The Device for Multiplying Polynomials Modulo an Irreducible Polynomial, News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2 (434), 2019, pp.199–205

[8] O.Veselska, O.Lavrynenko, R.Odarchenko, M.Zaliskyi, D.Bakhtiiarov, M.Karpinski, S.Rajba, A Wavelet-Based Steganographic Method for Text Hiding in an Audio Signal, Sensors, 22 (15), 5832, 2022. DOI:10.3390/s22155832

[9] R.Khurana, Y.Han, R.I.Arriaga, SMSpress: An SMS research management system, 6th International Conference on Mobile Computing, Applications and Services, 2014, pp. 75–81. DOI:10.4108/icst.mobicase.2014.257791

[10] J.O.Aasha, S.Monica, E.Brumancia, A Tracking System with High Accuracy Using Location Prediction and Dynamic Threshold For Minimizing SMS Delivery, International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC), 2015, pp. 1–6. DOI:10.1109/ICCPEIC.2015.7259516

[11] M.I.O. Hajahmed, K.E.M. Osman and O.T.M. Ali, Approaches for SMS Encryption and User Accounts Verification, 2020 International Conference on Computer, Control, Electrical, and Electronics Engineering, 2021, pp. 1–5. DOI:10.1109/ICCCEEE49695.2021.9429652

[12] I.V.Ostroumov, N.S.Kuzmenko, Statistical Analysis and Flight Route Extraction from Automatic Dependent Surveillance-Broadcast Data, 2022 Integrated Communications Navigation and Surveillance Conference (ICNS), Dulles, USA, April 5-7, 2022, pp. 1–9. DOI:10.1109/ICNS54818.2022.9771515

[13] Y.C.Sung, J.-F.Sung, Short Message Service for Internet-Mobile Platform, 2013 15th Asia-Pacific Network Operations and Management Symposium (APNOMS), 2013, pp. 1–3

[14] Q.Cai, Y.Tian, H.Li, T.Xu, Study of the SMS Platform Optimization Technology Based on Sliding Window and Load Balancing Mechanism, Seventh Web Information Systems and Applications Conference, 2010, pp. 185–189. DOI:10.1109/WISA.2010.27

[15] I.V.Ostroumov, N.S.Kuzmenko, Configuration Analysis of European Navigational Aids Network, 2021 Integrated Communications Navigation and Surveillance Conference (ICNS), Dulles, USA, April 19-23, 2021, pp. 1–9. DOI:10.1109/ICNS52807.2021.9441576
[16] F.Giménez, C.Zerbini, G.Riva, Extending SMS Service Coverage in Rural Areas by using LoRa Communication Technology, IEEE Latin America Transactions, 18 (02), 2020, pp.214–222. DOI:10.1109/TLA.2020.9085273
[17] S.-I.Sou, Y.-B.Lin, C.-L.Luo, Cost Analysis of Short Message Retransmissions, IEEE Transactions on Mobile Computing, 9 (2), 2010, pp.215–225. DOI:10.1109/TMC.2009.104
[18] R.Ayswarya, D.Sarala, P.Muralidharan, M.Ilankadhir, Service Quality of Mobile Banking Services in ICICI Bank Limited, Journal of Service Science and Management, 12, 2019, pp.649–664. DOI:10.4236/jssm.2019.125045
[19] I.V.Ostroumov, K.Marais, N.S.Kuzmenko, Aircraft Positioning using Multiple Distance Measurements and Spline Prediction, Aviation, 26 (1), 2022, pp. 1–10. DOI:10.3846/aviation.2022.16589
[20] O.Solomentsev, M.Zaliskyi, T.Herasymenko, Yu.Petrova, Data Processing Method for Deterioration Detection During Radio Equipment Operation, Microwave Theory and Techniques in Wireless Communications (MTTW 2019), Riga, Latvia, October 1-2, 2019, pp. 1–4. DOI:10.1109/MTTW.2019.8897232
[21] O.Solomentsev, M.Zaliskyi, O.Shcherbyna, O.Kozhokhina, Sequential Procedure of Changepoint Analysis During Operational Data Processing, 2020 IEEE Microwave Theory and Techniques in Wireless Communications (MTTW), Riga, Latvia, October 1-2, 2020, pp. 168–171. DOI:10.1109/MTTW51045.2020.9245068
[22] ETSI TS 102 250-2 v.2.7.1 (2019-11), Speech and multimedia Transmission Quality. QoS aspects for popular services in mobile networks. Part 2: Definition of Quality of Service parameters and their computation, 2019. URL: https://www.etsi.org/deliver/etsi_ts/102200_102299/10225002/02.07.01_60/ts_10225002v020701p.pdf
[23] What is P2P SMS? , 2020. URL: https://thesmsworks.co.uk/blog/p2p-sms/
[24] J.Al-Azzeh, A.Mesleh, M.Zaliskyi, R.Odarchenko, V.Kuzmin, A Method of Accuracy Increment Using Segmented Regression, Algorithms, 15 (10), 378, 2022, pp. 1–24. DOI: 10.3390/a15100378