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PAPER

Changes in Calling Parties' Behavior Caused by Settings for Indirect Control of Call Duration under Disaster Congestion

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SUMMARY The road space rationing (RSR) method regulates a period in which a user group can make telephone calls in order to decrease the call attempt rate and induce calling parties to shorten their calls during disaster congestion. This paper investigates what settings of this indirect control induce more self-restraint and how the settings change calling parties' behavior using experimental psychology. Our experiments revealed that the length of the regulated period differently affected calling parties' behavior (call duration and call attempt rate) and indicated that the 60-min RSR method (i.e., 10 six-min periods) is the most effective setting against disaster congestion.

key words: *disaster congestion, human behavior, communication behavior, self-restraint, indirect control, experimental psychology, call duration, call attempt rate, road space rationing*

1. Introduction

In the aftermath of a large-scale disaster such as a massive earthquake, people want to call their friends and family in the affected area out of concern for their safety. However, they can hardly get through because calls over the telephone network suddenly become concentrated in the disaster-affected area, easily overloading the area's network. For example, the 2011 Great East Japan Earthquake made people generate 60 and 40 times the normal numbers of outgoing and incoming calls, respectively, in the Tohoku area (the most devastated area) than around the same time on an ordinary day [1], [2]. Also, the 2004 Chuetsu Earthquake in the central part of Niigata Prefecture resulted in approximately 50 times as many calls as normal directed to Niigata Prefecture from all over Japan [3]. Similarly, the 1995 Great Hanshin-Awaji Earthquake resulted in approximately 50 times as many calls as normal in the busiest hour of the day (peak hour) on an ordinary day directed to the Kobe area (the most devastated area) [3], [4].

Many methods have been proposed to make it easier for calls to get through to a disaster-affected area [5]. Tanaka et al. [6] focused on a chat system using peer-to-peer (P2P) communication and solved the problem by developing a communication infrastructure that can handle communications even without the Internet. Kamruzzaman et al. [7] solved the problem by using Internet of Things (IoT) based device-to-device ad hoc networking. Bakheet et al. [8] avoid network congestion by using an alternative path such as Internet connections. Although these methods are effective, they might not provide enough network resources against sharp increases in traffic caused by disaster congestion. A network design method has been proposed to increase available network resources by load balancing [9]–[11]. It uses network resources in non-damaged areas to meet communication demand in damaged areas by allocating users who are almost evenly located around the country to each session initiate protocol (SIP) server by using subscriber extension numbers. It is effective because a disaster generally does not strike nationwide but in parts of a region. However, this method has to update a whole network and is effective in only a SIP network that uses telephone numbers with area codes, i.e., landlines. Usage-restriction approaches have also been proposed to solve the problem. Methods that directly restrict demand have been proposed [12]–[14]. Limitation of call attempts [12], [13] prevents ineffective call attempts from wastefully consuming network resources. However, unsuccessful call attempts are repeated, and the method is not a sufficient countermeasure against disaster congestion. The method to limit call duration [14] provides an opportunity for more people to call and is expected to mitigate disaster congestion earlier. People try to finish calls in the limited period after a warning that time will soon be up. This was discussed as a practical method in the study group on maintaining communication capabilities during major natural disasters and other emergency situations in the Ministry of Internal Affairs and Communications of Japan [1] after the 2011 Great East Japan Earthquake. The group's final report [1] states that the method is seen as an effective countermeasure against congestion, but that terminating a connection would produce repeated unsuccessful call attempts [15], which wastefully consume resources. Direct restriction methods inevitably make people attempt more calls, which worsens congestion as described above.

To reduce congestion, indirect restriction methods are preferable because they prevent people from making repeated unsuccessful call attempts. However, they require mechanisms to change people's communication behavior. Niida et al. [16] proposed an indirect control method to enable people to choose an appropriate network by visualizing network usage history, although it is not a countermeasure against disaster congestion. Their mechanism to change people's behavior uses entertaining content, such as video games.

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Their field studies found that 28% of participants changed their behavior. Satoh et al. proposed a hybrid restriction method called a road space rationing (RSR) method [17] that directly restricts the period in which to make calls for a user group. This direct restriction of a period in which to make call yields indirect control of call duration. Limiting the period in which to make calls inhibits people from making long calls because they are eager to quickly find out whether their friends and family are safe and do not want to wait until the next period. This is a mechanism to change people's communication behavior. Their experiment shows call duration is reduced by 30% when six minutes in one hour are assigned as a period in which to make calls for a user group.

In this paper, we investigate which of the various possible settings in the RSR method is the most effective and observe how the settings change calling parties' behavior on the basis of experimental psychology. Satoh et al. [17] showed that the RSR method reduces call duration despite not restricting call duration by restricting the period in which to make a call. The RSR method restricted the period to a six-minute assigned period in one hour as just one example. Various restrictions (settings) of the RSR method are possible. Observing how the settings change calling parties' behavior is essential to realize the RSR method because the reduction against disaster congestion directly depends on calling parties' behavior in the RSR method. However, the change has not yet been observed. This paper focuses on how the settings reduce call duration as the performance of the RSR method and increase the call attempt rate as a side-effect of the RSR method.

The rest of this paper is structured as follows. Section 2 introduces the RSR method. In Sect. 3, we present experiments for three settings: 10-, 30-, and 90-min RSR. Section 4 shows the results for the conscious reduction of the call duration by inducing caller self-restraint, and Sect. 5 shows the results for the rate of unsuccessful call attempts and the relationship between call duration and the rate of unsuccessful call attempts. Finally, Sect. 6 concludes the paper with a summary.

2. RSR Method

The RSR method [17] restricts the period for outgoing calls but not periods of incoming calls or the call duration. A group of users is permitted to make calls only in one-tenth of a certain period (e.g., six minutes in one hour), and each group is assigned a different time. All users can answer the phone anytime but can make calls only in their assigned period. Users can continue calls without a time restriction. The users are classified into ten groups on the basis of the last digits of their phone numbers. Each group has the same number of users, and the locations of the users in a group are uniformly distributed [11]. Both properties are effective against disaster congestion because they level load.

The details of the 60-min RSR method are illustrated in Fig. 1. Thus, each group is assigned six minutes as a period for making calls. Digits 0-9 in Fig. 1 represent groups that have telephone numbers ending in 0-9. Members in each group can make calls only in the assigned period. For example, only users who belong to group 1 can make calls from XX:06 to XX:12, and others can never make calls in this period. If they try, their calls are blocked at the edge node and do not enter a network. All users can receive calls anytime. Users who belong to group 1 can continue to talk after XX:12 because call duration is not restricted.

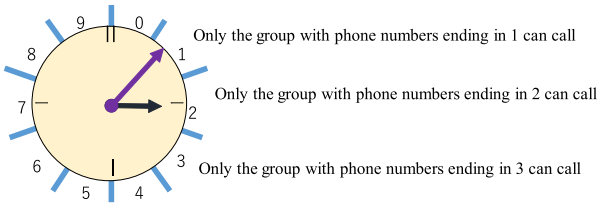


Fig. 1 Assigned time to groups.

The RSR method is implemented as follows. When a communication node in the affected area detects congestion, it sends a congestion message to a management system. After the management system receives the message, the system sends a restriction message to all communication nodes in the country. When a communication node receives the restriction message, it restricts calls to the congested nodes on the basis of periods assigned to callers. The communication node never restricts calls to uncongested nodes although it discards all calls to the congested nodes during unassigned periods for callers. After the congestion is over, the management system sends a control-removal message to all countrywide nodes.

The RSR method has the following benefits. It reduces the number of users who can make calls to one-tenth for each assigned period and prevents predominately unsuccessful attempts from wastefully consuming resources. Most users will not try to make a call in the non-assigned period because they know their call attempts will definitely fail. Users in their assigned period can contact their loved ones more easily because only one-tenth of the users can call. From Satoh et al. [17], the call attempt rate with the RSR method is between 1/8 and 1/7 when a group has 1/10 the users because the rate of call attempts for each person increases. Furthermore, it reduces not only call attempts but also users' call duration due to users' self-restraint. Users want to know that their loved ones are safe as soon as possible and try to avoid waiting until the next assigned period. They will inevitably feel time pressure due to restriction of the period in which to make a call, and this time pressure will motivate them to seek closure more quickly [18], [19]. They will thus reduce their call duration naturally. In fact, Satoh et al. [17] showed that the 60-min RSR method reduced call duration by 30%. The reduction in call duration moderately mitigates congestion and improves the call completion ratio sooner.

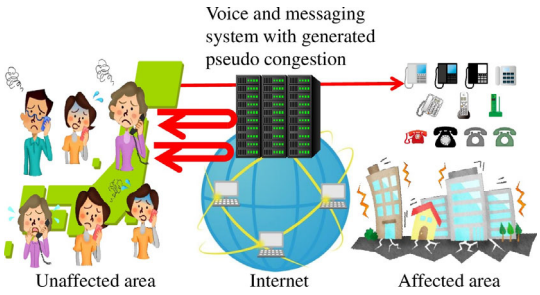


Fig. 2 Telephone system for experiments.

3. Experiments

The effect of the reduction in call duration might depend on the lengths of a certain period, that is, assigned and non-assigned times for a group. We conducted psychological experiments using 10-, 30-, and 90-min RSR methods to determine the most effective RSR period length. We measured the call duration and calling rate for each case.

3.1 System

We used the same system as Satoh et al. [17]. Figure 2 shows the system that enables pseudo congestion and control on the basis of the RSR method on a cloud application programming interface (API) for the voice and messaging system Tropo [20]. In our experiments, the conventional method was simulated by blocking calls with a given probability as the call-blocking ratio. The system announced a prerecorded statement to a participant as a calling party when a call was blocked in his/her assigned period: "The network is congested. Call again later, please." The RSR method was simulated by blocking calls with another probability and announcing the same statement as above. Furthermore, the system blocked all calls in non-assigned periods and announced another prerecorded statement to a participant as a calling party when he/she made a call outside his/her assigned period: "It is not currently your assigned period for making a call. Your assigned period is from XX:XX to XX:XX."

3.2 Call-Blocking Ratio

The call-blocking ratio B is given with offered traffic intensity a_o and carried traffic intensity a_{cr} as

$$B = \frac{a_o - a_{cr}}{a_o}. \tag{1}$$

We gave the carried traffic intensity a_{cr} to meet the call-blocking ratio of 0.1 when a_o is maximum during ordinary times. The call-blocking ratio was based on NTT's call-blocking ratio during ordinary times, which is equal to or less than 10% [21]. Therefore, the following equation holds,

$$0.1 = \frac{a_{max} - a_{cr}}{a_{max}}. \tag{2}$$

Table 1 Experiment date and time.

Date	Start	End	Period (min)	# of calling party	# of called party
1/19	13:12	16:12	90	10	8
1/20	13:21	16:23	90	10	9
1/23	13:12	16:14	90	10	7
1/24	13:21	16:21	30	10	9
1/25	13:12	16:12	30	10	9
1/26	13:15	16:16	30	10	9
1/27	13:35	15:55	10	10	9
1/30	13:30	16:39	10	10	9
1/31	13:30	15:55	10	10	9

Thus, we obtained

$$a_{cr} = \frac{9}{10} a_{max}, \tag{3}$$

from Eq. (2).

The maximum traffic intensity was actually reported to be 50 times [3], [4] and 60 times [1] higher than that during ordinary times during the 1995 Great Hanshin-Awaji Earthquake and 2011 Great East Japan Earthquake, respectively. However, we adopted 20 times higher traffic intensity than that during ordinary times as the maximum in disaster congestion to avoid causing participants too much stress. The value was the same as that in Satoh et al. [17]. As a result, B_c with the conventional method was obtained as

$$B_c = \frac{20a_{max} - a_{cr}}{20a_{max}} = \frac{20a_{max} - \frac{9}{10}a_{max}}{20a_{max}} = 0.955. \tag{4}$$

We gave B_r for the RSR method as

$$B_r = \frac{2a_{max} - a_{cr}}{2a_{max}} = \frac{2a_{max} - \frac{9}{10}a_{max}}{2a_{max}} = 0.55, \tag{5}$$

because the maximum traffic intensity with the RSR method is one-tenth that with the conventional method, that is, twice as high as that during ordinary times if the rate of making a call for a calling party is conserved in both methods. A call was blocked with B_r during the assigned period.

3.3 Procedure

Experiments were conducted over three days each for the 90-, 30-, and 10-min RSR methods, for a total of nine days on 19th, 20th, 23rd, . . . , 27th, 30th, and 31st January, 2017. We formed 10 groups for each RSR method and assigned each group 9, 3, and 1 minutes within the 90, 30, and 10 minutes. Participants belonged to either calling parties or called parties and each participant as a calling party belonged to each group for each RSR method. There were 168 participants (5 males and 163 females) who lived in the Kanto area (in and around Tokyo). Details are shown in Table 1.

We gave each participant a different character profile,

his/her relationship with other characters, and a different situation on the disaster day. The character profiles were the same as those in Satoh et al. [17]. Each participant practiced his/her role in the morning and participated in the experiments in the afternoon. Ten participants played the roles of calling parties who lived in unaffected areas. Each participant belonged to a different group for the RSR method. The remaining participants played the roles of called parties who lived in an affected area. Experiments were conducted in four rooms: two rooms for the calling party participants and two other rooms for the called party participants. Each room had five or fewer participants.

Each calling party participant was given a list of the called parties that was the same as that in Satoh et al. [17] and was required to fill in blanks in the list regarding the damage situation for the called parties. The blanks in the list for each calling party were differently made for the damage situations of the same called party to avoid him/her guessing from the conversations of other calling parties in the same room. Each calling party asked the called parties questions to obtain information to fill in the blanks.

Each called party participant was given a document that described his/her damage situation that was the same as that in Satoh et al. [17] and had to answer various questions from the calling parties on the basis of the given document because all calling parties asked different questions to obtain the different information they wanted.

4. Results for Call Duration

To find out the most effective period for reducing call duration, we conducted our experiments for the 10-, 30-, and 90-min RSR methods and compared the results with those for the 60-min RSR method and the conventional method [17]. Table 2 summarizes the observed data. In our experiments, we arranged the order of called parties for calling parties to avoid busy calls. The actual blocking ratios of the system were relatively close to the designed ratios although the cases of the 10- and 30-min RSR methods included error as follows,

$$7992/8444 = 0.946 \simeq 0.955, \quad (6)$$

$$504/(1117 - 159) = 0.526 \simeq 0.55, \quad (7)$$

$$374/(807 - 159) = 0.577 \simeq 0.55, \quad (8)$$

$$454/(1021 - 190) = 0.546 \simeq 0.55, \quad (9)$$

$$275/(544 - 44) = 0.55. \quad (10)$$

Some calls were cut due to problems with the lines because the Internet may have been congested. Therefore, conversation was impossible in such calls. The connected calls and successful calls in Table 2 mean established calls and calls in which conversation was possible, respectively. We only focused on the successful calls regarding call duration.

We summarized the experimental results for call duration in Table 3. Table 3 shows the average, minimum, maximum, unbiased standard deviation (USD), standard error (SE), and reduction rate against the average call duration for the conventional method. Values in the parentheses in the Conv. column are values when the maximum datum was excluded because it was an outlier.

Table 2 Primary data.

	Conv. [17]	10 min	30 min	60 min [17]	90 min
Days	3	3	3	4	3
Total call attempts	8444	1117	807	1021	544
Calls blocked by pseudo congestion	7992	504	374	454	275
Successful calls	230	265	217	306	205
Connected calls*	284	454	274	317	225
Call attempts during non-assigned period	–	159	159	190	44
Busy calls	168	0	0	60	0

Table 3 Call duration.

	Conv. [17]	10 min	30 min	60 min [17]	90 min
Sample size	230	265	217	306	205
Average (s)	160.9 (159.2)	164.6	120.7	111.1	118.0
Min (s)	53	69	56	60	62
Max (s)	541 (352)	321	459	343	244
USD (s)	61.0 (55.6)	48.3	35.4	33.9	30.9
SE (s)	4.02	2.97	2.40	1.94	2.16
Reduction rate (%)	0	-2.30	25.0	31.0	26.7

4.1 Average

We compared the average call durations in the 10-, 30-, 60-, and 90-min RSR methods with that in the conventional method. Figure 3 shows the average and SE of call duration. The average call durations for the 30-, 60-, and 90-min RSR methods were shorter than that for the conventional method. However, the average call duration for the 10-min RSR method was longer.

The number of called parties might affect call duration. Although the number of called parties was 10 for the 60-min RSR method and the conventional method, it was 9 for the 10- and 30-min RSR methods and was different for the 90-min RSR method on each experiment day as shown in Table 1. We conducted an analysis of variance (ANOVA) test on the averages call duration of the 90-min RSR method for the data on the three experiment days because the difference was only the number of called parties. A null hypothesis H_0 that the average call durations on 19th, 20th, and 23rd

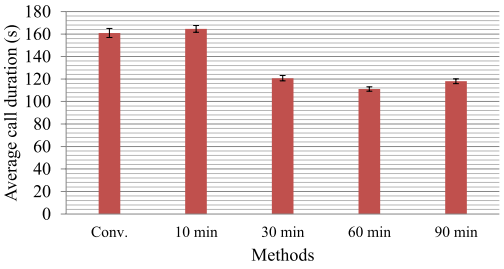


Fig. 3 Histogram of call duration.

January were drawn from the same population:

$$H_0 : \mu_{19th} = \mu_{20th} = \mu_{23rd},$$

where μ_{19th}, μ_{20th}, and μ_{23rd} are the average call durations of the 19th, 20th, and 23rd January experiments. The H_0 was accepted with a significance level of 5% because

$$F = 0.3560,\ p = 0.70, \tag{11}$$

where the p-value was calculated on the basis of an F-distribution $F(2, 202)$ with 2 and 202 degrees of freedom. Therefore, the number of called parties was independent of the average call duration for the 90-min RSR method. Other cases also must be independent of the average call duration.

Since we excluded the number of called parties as a reason for reducing call duration, the assigned period influenced the reason. Then, we conducted an ANOVA test on the average call durations for all methods. A null hypothesis H_0 that the average call durations of the 10-, 30-, 60-, 90-min RSR, and conventional methods groups were drawn from the same population:

$$H_0 : \mu_{10} = \mu_{30} = \mu_{60} = \mu_{90} = \mu_c,$$

where $\mu_{10}, \mu_{30}, \mu_{60}, \mu_{90}, \mu_c$ are the average call durations of the 10-, 30-, 60-, 90-min RSR, and conventional methods. The H_0 was rejected with a significance level of 0.1% because

$$F = 83.34,\ p < 2.0 \times 10^{-16}, \tag{12}$$

where the p-value was calculated on the basis of an F-distribution $F(4, 1218)$ with 4 and 1218 degrees of freedom. Then, we conducted Welch's T-test for pairwise comparisons with the Benjamini-Hochberg (BH) method [22]. Table 4 shows p-values for each pairwise comparison. Null hypotheses $\mu_{30} = \mu_c$, $\mu_{60} = \mu_c$, $\mu_{90} = \mu_c$ and $\mu_{30} = \mu_{10}$, $\mu_{60} = \mu_{10}$, $\mu_{90} = \mu_{10}$ were rejected with significance levels of 0.1% at (†), 1% at (**), 5% at (*) in Table 4. The tests revealed that the average call durations of the 60-min RSR method became shorter than those of the 30- and 90-min RSR methods and that those of the 30- and 90-min RSR methods became shorter than those of the 10-min RSR and conventional methods.

Only the 10-min RSR method did not have shorter average call durations than the conventional method although the other RSR methods did. The participants in the 10-min RSR method did not seem to feel time pressure to shorten their call duration. They presumably thought that it was impossible to make two or more calls in so short an assigned period (one minute) although they could not have known this in advance. In fact, the shortest call duration was longer than one min from Table 3. This means only one call can be made in the assigned period (one minute) for the 10-min RSR method. All the participants might have given up any intention of making two or more calls in one minute in advance. If they do not give up, call duration will depend on the starting time of a call. If a calling party makes a call at the beginning in the one minute, he/she will try to call for a shorter time. Otherwise, he/she will call for longer. However, there was no relationship between starting time and call duration because the correlation relation r between starting time and call duration was calculated as

Table 4 Call duration.

	10 min	30 min	60 min	90 min
Conv.	$4.54E-1$	$4.27E-16^{\dagger}$	$2.45E-24^{\dagger}$	$1.62E-18^{\dagger}$
10 min	-	$1.06E-26^{\dagger}$	$3.57E-41^{\dagger}$	$3.81E-31^{\dagger}$
30 min	-	-	$2.99E-3^{**}$	$4.54E-1$
60 min	-	-	-	$2.23E-2^{*}$

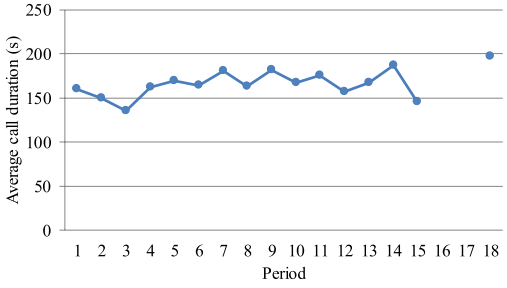


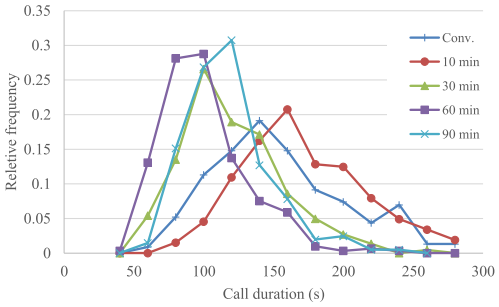
Fig. 4 Average call duration in each assigned period.

$$r = -0.10858 \simeq 0. \tag{13}$$

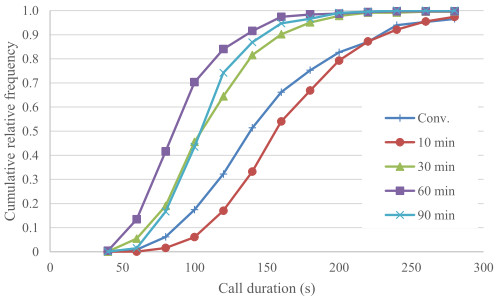
The participants did not learn that making two or more calls was impossible in the assigned period in the second or later periods from their own experience in the first period although they had 18 periods in the three-hour experiment. The average call duration in the second or later periods was not longer than that in the first period as shown in Fig. 4. Therefore, the participants did not seem to try to shorten their calls from the first to later periods.

4.2 Relative Frequency

To investigate what caused the difference in the average call duration between the 30-, 60-, and 90-min RSR methods, we analyzed how the assigned periods of RSR methods affect the distribution of call duration. The relative frequencies (RFs) and cumulative relative frequencies (CRFs) of call duration are illustrated in Fig. 5. The conventional method and the RSR methods had different modes except those of 30- and 60-min RSR methods from Fig. 5(a). The RF of the 10-min RSR method was shifted to a longer call duration than that



(a) Relative frequencies.



(b) Cumulative relative frequencies.

Fig. 5 Relative and cumulative relative frequencies of call duration.

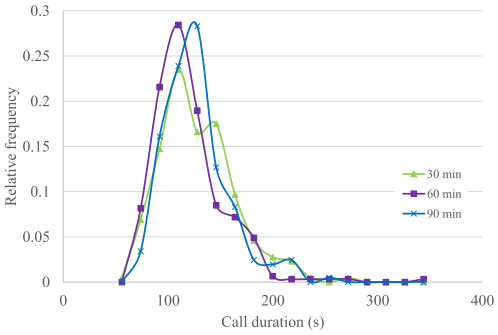


Fig. 6 Relative Frequency of 30-, 60-, and 90-min RSR methods.

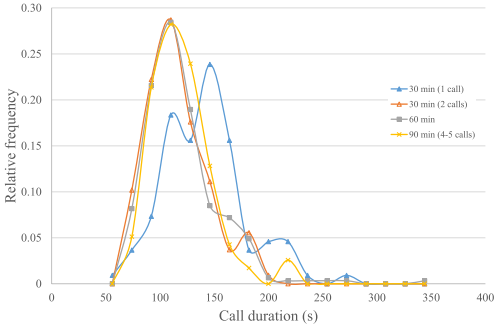


Fig. 7 Relative frequency of 30- (one-call class), 30- (two-call class), 60-, and 90- (four- or five-call class) min RSR methods.

of the conventional method. Therefore, the difference in the average call duration between the conventional and the 10-min RSR methods depended on the difference between both RFs. The CRF of 60-min RSR method was more than those of the other methods when the call duration was less than 200 s as shown in Fig. 5(b). The CRF of the 90-min RSR method was more than that of the 30-min RSR method when the call duration was between 100 s and 160 s. The CRF of the 10-min RSR method was lower than that of the conventional method when the call duration was less than 220 s.

Figure 6 shows distributions as histograms of RF for the 30-, 60-, and 90-min RSR methods. The shapes of distributions of the 60- and 90-min RSR methods are similar to each other but different from that of the 30-min RSR method from Fig. 6. Moreover, the 90-min RSR method was less effective for reducing call duration than the 60-min RSR method because the peak of the distribution of the 90-min RSR method is larger than that of the 60-min RSR method. Overall, calling parties in the 90-min RSR method made longer calls than those in the 60-min RSR method.

We classified call duration data of the 30-min RSR method into data in one call and two calls and selected call duration data of the 90-min RSR method from four and five calls in the assigned period. Then, we illustrated distributions as histograms of RF for each class in Fig. 7. The shapes of the distributions of the 30-min (two calls) and 60-min RSR methods matched, especially for short call durations, whereas the distribution of the 30-min (one call) RSR method shifted to a longer call duration. The one call

Table 5 Frequency for 1-3 and 4-5 calls in 90-min RSR method.

Calls	Frequency
1-3	31
4-5	29

Table 6 Frequency for one and two calls in 30-min RSR method.

Calls	Frequency
1	109
2	108

accounted for 50% as shown in Table 6. This is why the 30-min RSR method is less effective than the 60-min one. The distribution of the 90-min (four or five calls) slightly shifted to a longer call duration than those of the 30-min (two calls) and 60-min RSR methods. Calling parties who made one to three calls in the 90-min RSR method had longer average call durations than calling parties who made four or five calls. This result seems to indicate that the calling parties who made four or five calls in the 90-min RSR method feel weaker time pressure to shorten their call duration than the other parties in the 30-min (two calls) and 60-min RSR methods because they had the longest assigned period (nine minutes). Also, the four or five calls in the assigned period accounted for almost 50% as shown in Table 5. This is why the 90-min RSR method is less effective than the 60-min one.

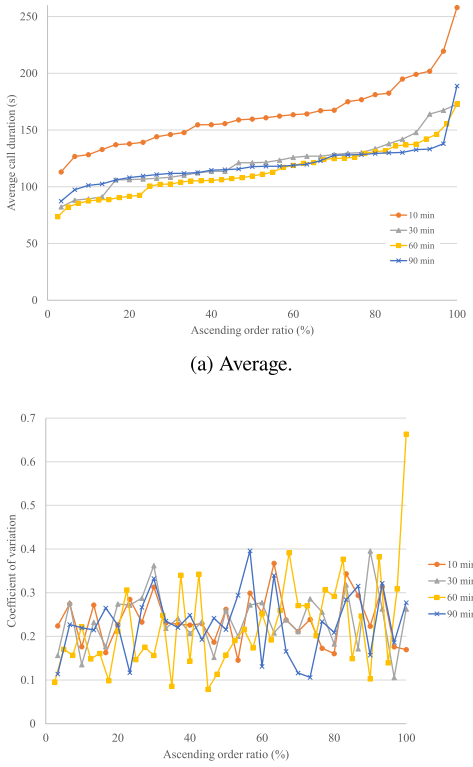
The reason for the lower effectiveness of the 30-min RSR method seemed to be different from that of the 90-min

RSR method because only the distribution of the 30-min (one call) had two peaks in Fig. 7. The two peaks indicated that there were two types of calling parties who belonged to the one-call class in the 30-min RSR method. One type seemed to give up making two or more calls in their assigned period due to weak time pressure. This is the same as the cause of ineffectiveness in the 90-min RSR method. The other type seemed to try to make two or more calls but did not have enough time because the call duration at the smaller peak was the same as those at the peaks in the 30-min (two calls) and 60-min RSR method. Calling parties in the 30-min RSR method must not only shorten call durations but also get through in a short time to make two calls in the assigned period. Moreover, calling parties in the 30-min RSR method made at most two calls in the assigned period. If the calling parties make a slightly longer call, making another call is difficult due to the short assigned period (three minutes). The calling parties cannot offset the longer call duration by the other call due to the short assigned period although calling parties in the 60-min RSR method can. As a result, the effect of time pressure leads to calling parties not fully making use of the shortened call duration in the 30-min RSR method.

4.3 Behavioral Analysis of Calling Parties

We measured the average call duration by a calling party and arranged the average intervals in ascending order because the reduction in the call duration was due to the calling parties [17]. The RSR method affects behavior of calling parties because the method regulates behavior of calling parties but not that of called parties. The purpose was to understand how the assigned periods of RSR methods changed the average call duration by a calling party. The measurement results are shown in Fig. 8(a), where the numbers of calling parties were normalized because there were more in the 60-min RSR method (40) than in the other RSR methods (30). We also measured the coefficient of variation (CV) for a calling party as a measurement of the dispersion of call durations in a calling party and arranged the average call durations in ascending order as shown in Fig. 8(b). We did not adopt the USD as a measurement of the dispersion of call duration because it depends on the average call duration, which differs for calling parties. We had to exclude the bottom value of the 60-min RSR method because the CV was much larger than other data when we analyzed data.

We investigated how the assigned periods of RSR methods affected the average call duration for calling parties from Fig. 8(a). Each calling party in the 10-min RSR method made longer calls than each calling party in the other RSR methods in the same order. On the whole, the 10-min RSR method was not effective at reducing call duration. Both the 30- and 90-min RSR methods were similarly effective at reducing call duration for the 20% to 80% order calling parties. The 60% calling parties in the 60-min RSR method made shorter calls than those in the other RSR methods. These results were consistent with the test results in Table 4. The



(a) Average.

(b) CV.

Fig. 8 Call duration by calling party.

average call durations were nearly flat for all calling parties except the top and bottom calling parties of the 90-min RSR method, whereas the 30-min RSR method was more effective for the top 15% calling parties but not for the bottom 10%. The bottom 10% calling parties in the 30-min RSR method seemed to give up making more calls because at most two calls were possible in the assigned period. Also, the 60-min RSR method was more effective for the top 25% calling parties. Thus, the reason the 60-min RSR was the most effective was that it was more effective for 60% calling parties and much more effective for 25% calling parties than the other RSR methods.

4.4 Call Duration and Number of Calls in the Assigned Period

We analyzed the effectiveness of the 60-min RSR method with the relationship between call duration and the number of calls in an assigned period. We measured the average call durations with the SE for the number of calls in the assigned periods in the 30-, 60-, and 90-min RSR methods. We excluded the 10-min RSR method because the number of calls was only one in the assigned period. The results are shown in Fig. 9 and Tables 7, 8, and 9. Values in parentheses in Tables 7, 8, and 9 are the SE, and there is no SE in the case of five calls in nine minutes because only one case was observed. The average decreased as the number of calls increased for the 30-, 60-, and 90-min RSR methods from

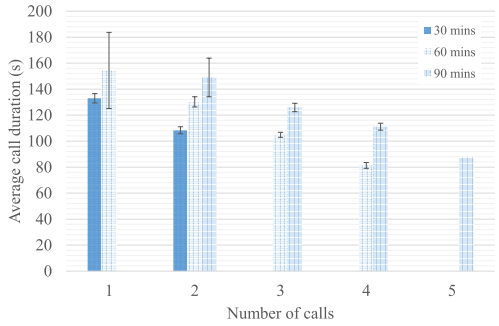


Fig. 9 Average call duration by number of calls.

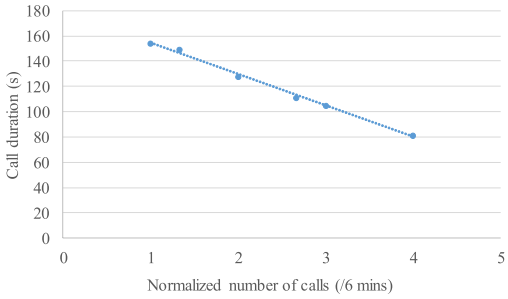


Fig. 10 Average call duration by normalized number of calls.

Table 7 Average call duration by number of calls in 30-min RSR method.

# of calls	Size	All	1st	2nd
All	217	120.7	-	-
1	109	132.9	132.9	-
		(3.6)	(3.6)	-
2	54	108.3	100.1	116.5
		(2.7)	(2.6)	(4.5)

Table 8 Average call duration by number of calls in 60-min RSR method.

# of calls	Size	All	1st	2nd	3rd	4th
1	8	154.4	154.4	-	-	-
		(29.3)	(29.3)	-	-	-
2	40	130.2	132.5	127.9	-	-
		(4.0)	(6.3)	(4.9)	-	-
3	66	104.9	100.1	105.5	109.0	-
		(2.2)	(2.8)	(3.2)	(3.7)	-
4	5	81.3	84.3	80.6	78.4	82.1
		(3.0)	(5.9)	(6.0)	(3.6)	(2.4)

Table 9 Average call duration by number of calls in 90-min RSR method.

# of calls	Size	All	1st	2nd	3rd	4th	5th
1	0	-	-	-	-	-	-
2	5	149.0	150.2	147.8	-	-	-
		(14.8)	(19.9)	(24.4)	-	-	-
3	26	125.9	131.0	120.6	126.2	-	-
		(3.2)	(5.1)	(5.2)	(6.3)	-	-
4	28	111.1	108.1	103.0	112.1	121.3	-
		(2.6)	(4.3)	(4.3)	(5.3)	(6.6)	-
5	1	88.0	113.0	85.0	71.0	94.0	77.0

Fig. 9.

To analyze the relationship between call duration and the number of calls in the assigned period, we compared the 90- and 60-min RSR methods. We excluded the 30-min RSR method because it had coarse granularity as only one and two calls and had a different distribution of call duration from those in the other two RSR methods as shown in Sect. 4.2, whereas the 60- and 90-min RSR methods had similar distributions as shown in Sect. 4.2. Moreover, we excluded five calls in the 90-min RSR method because the sample size was one. We have to normalize the number of calls in the assigned period to compare the three RSR methods because two calls in the 30-, 60-, and 90-min RSR methods were not able to be treated equally. We normalized the number of calls in the 90-min RSR method to that in the 60-min RSR method by multiplying the number of calls in the 90-min RSR method by $2/3(= 6/9)$. For example, the three calls in the 90-min RSR method were normalized to two calls. The normalized number of calls is shown in Fig. 10, where we used the average of the 60- and 90-min RSR methods as the value for two calls and excluded five calls in the 90-min RSR method because the sample size was one. A regression equation:

$$y = -24.914x + 179.6, \tag{14}$$

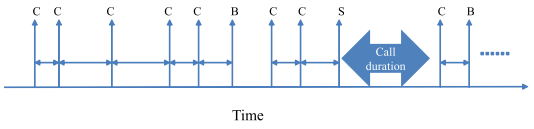
was obtained between call duration and the number of calls, where x and y represent the number of calls in the assigned period (six mins) and the average call duration. Eq. (14) well describes the relationship between the number of calls in the assigned period and the call duration because the coefficient of determination R^2 is 0.996. Thus, Eq. (14) gives the extra calls that an average calling party can make in one hour due to reduced call duration by changing the 60-min RSR method to the 90-min one. Since the average call durations for 60- and 90-min RSR methods were 111.1 s and 118.0 s, Eq. (14) gives the extra call in the assigned period (six minutes),

$$\frac{179.6 - 111.1}{24.914} - \frac{179.6 - 118.0}{24.914} = 0.277. \tag{15}$$

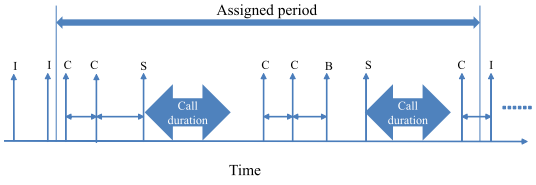
Therefore, an average calling party can make 2.8 more calls per hour in the 60-min RSR method than in the 90-min one under the same call-blocking ratio assumption.

5. Results for Call Attempt Rate

We are also interested in the change in the rate of unsuccessful call attempts depending on RSR methods because a much higher rate due to the RSR method can cancel out the effect of easing congestion by limiting the number of calling parties. In fact, the rate of the call attempts in the 60-min RSR method is higher than that in the conventional method [17] because the period in which to make calls is limited. However, the effect of increasing the call attempt rate by the RSR method is equivalent to a value between 1/8 and 1/7



(a) Conventional method.



(b) RSR method.

Fig. 11 Measured subject of intervals.

when a group has 1/10 the users [17].

5.1 Average

We conducted experiments to investigate how the rate of the call attempts depends on the length of the assigned period even though all the RSR methods limit them. We directly measured the intervals between adjoining calls for a calling party and obtained the rate of the call attempts for a calling party as the reciprocal of the average interval. The measured intervals were not all intervals between adjoining calls but intervals shown as double-sided thin arrows in Fig. 11, that is, intervals when the first call was congested (C). Moreover, the first call had to be included in the assigned period in the case of the RSR method. Intervals when the first call was busy (B) or successful (S) were excluded because calling parties tended to take longer to make new calls than in the case of C. A calling party tended to wait intentionally when he/she heard a busy tone (B) and made a new call after finishing a call (S). Invalid calls (I) in the RSR method were also excluded because not all invalid calls were made just before or just after the assigned period and some calling parties made invalid calls in the middle between the adjoining assigned periods. The criteria for the measured intervals were the same as those in Satoh et al. [17].

We summarize experiment results on the average interval between the adjoining call attempts for a calling party as a reciprocal of the average call attempt rate in Table 10, which shows sample size, maximum, minimum, average, SE, USD, median, mode, CV, and rate normalized by rate of the conventional method. The average intervals of the 10-, 30-, and 60-min RSR methods were shorter than that of the conventional method from Fig. 12. However, the average interval of the 90-min RSR method was almost the same as that of the conventional method. That is, the normalized rate of the 90-min RSR method was lower than one although those of the others were higher than one. This is not due to an outlier because the maximum was 104 s for the 90-min RSR method against 203 s for the 60-min RSR method.

We conducted the ANOVA test on the averages of the

Table 10 Intervals between adjoining calls.

	Conv. [17]	RSR			
		10 min	30 min	60 min	90 min
Sample size	7925	451	373	453	274
Max (s)	1743	58	52	203	104
Min (s)	5	7	7	4	6
Average (s)	16.21	13.16	12.94	12.02	16.30
SE (s)	0.31	0.27	0.35	0.56	0.65
USD (s)	27.54	6.08	6.78	11.97	10.69
Median (s)	11	11	11	10	13
Mode (s)	9	11	8	10	11
CV	1.70	0.46	0.52	1.00	0.66
Normalized rate	1.00	1.23	1.25	1.35	0.99

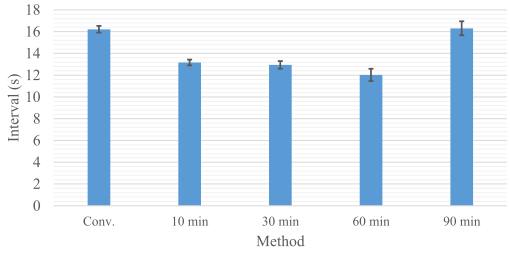


Fig. 12 Histogram of average interval.

intervals between adjoining call attempts to show the above results. A null hypothesis H_0 was that the average intervals between the call attempts of the 10-, 30-, 60-, and 90-min RSR, and conventional methods groups were drawn from the same population:

$$H_0 : \frac{1}{\lambda_{10}} = \frac{1}{\lambda_{30}} = \frac{1}{\lambda_{60}} = \frac{1}{\lambda_{90}} = \frac{1}{\lambda_c},$$

where $\lambda_{10}, \lambda_{30}, \lambda_{60}, \lambda_{90}$, and λ_c were the rate of the call attempts in the 10-, 30-, 60-, and 90-min RSR, and conventional methods. The null hypothesis H_0 was rejected with a significance level of 0.1% because

$$F = 23.566,\ p < 2.2 \times 10^{-16}. \tag{16}$$

Then, we conducted Welch's T-test for pairwise comparisons with the BH method [22]. Table 11 shows p-values for each pairwise comparison. Null hypotheses $1/\lambda_{10} = 1/\lambda_c, 1/\lambda_{30} = 1/\lambda_c, 1/\lambda_{60} = 1/\lambda_c$, $1/\lambda_{10} = 1/\lambda_{90}, 1/\lambda_{30} = 1/\lambda_{90}$, and $1/\lambda_{60} = 1/\lambda_{90}$ were rejected with significance levels of 0.1% at (†) in Table 11. We obtained the statistical differences between groups of the 90-min RSR and conventional methods and the groups of other RSR methods from the above tests. The average intervals of the RSR methods except the 90-min one became shorter than that of the conventional method, and there were no differences between the 10-, 30-, and 60-min RSR methods. Calling parties for the 90-min RSR and conventional methods attempted calls at the same rate even though the period in which to make a call was restricted for the 90-min RSR

Table 11 Interval.

	10 min	30 min	60 min	90 min
Conv.	$1.91E-12^{\dagger}$	$2.49E-11^{\dagger}$	$4.16E-10^{\dagger}$	$9.02E-01$
10 min	-	$6.94E-01$	$9.84E-02$	$1.70E-05^{\dagger}$
30 min	-	-	$2.06E-01$	$1.32E-05^{\dagger}$
60 min	-	-	-	$1.94E-06^{\dagger}$

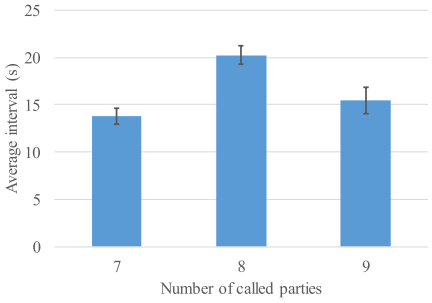


Fig. 13 Histogram of average interval for called parties.

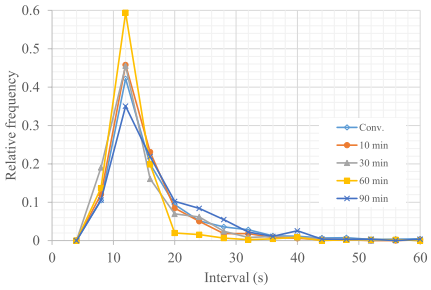
method but not for the conventional method.

The number of called parties in the 90-min RSR method might have caused the above test results because it was less than those in other RSR methods as shown in Table 1 and Satoh et al. [17]. Fewer called parties should bring about a longer average interval. However, Fig. 13 does not show such a result, where Fig. 13 shows the average intervals for the number of called parties in the 90-min RSR method with the SEs as shown in Fig. 13. Thus, the number of called parties did not cause the interval in the 90-min RSR method to be longer than those in the other RSR methods.

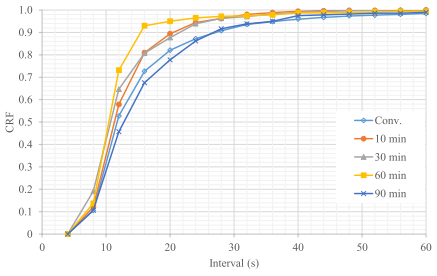
5.2 Relative Frequency

To investigate the rates of the call attempts for all the methods more deeply, we analyzed the RFs and CRFs as shown in Fig. 14, where we selected times from 0 to 60 s for ease of understanding. The CRF between 0 to 60 s occupied 98.4%, 100 %, 100%, 99.3%, and 98.9% for the conventional and 10-, 30-, 60-, and 90-min RSR methods, respectively. Figure 14(a) illustrates that the relative frequency decreased as the interval increased for all methods and that all methods had almost the same mode although modes of call duration were different between the methods in Fig. 5. The interval less than 20 s for all the methods represented a large part of the interval from Fig. 14(b). The CRFs of the 90-min RSR method and the conventional method were less than those of the 10-, 30-, and 60-min RSR methods at intervals of 12 s or longer as shown in Fig. 14(b). This is consistent with the results in the previous section.

Although there were no statistical differences between the 10-, 30-, and 60-min RSR methods, calling parties must have behaved differently because a calling party made only one call in the 10-min RSR method and at most two calls in the 30-min RSR method despite making one to four calls in the 60-min RSR method in each assigned period. There appear to be three groups (60-min RSR, 10- and 30-min



(a) Relative frequencies of intervals.



(b) Cumulative relative frequencies of intervals.

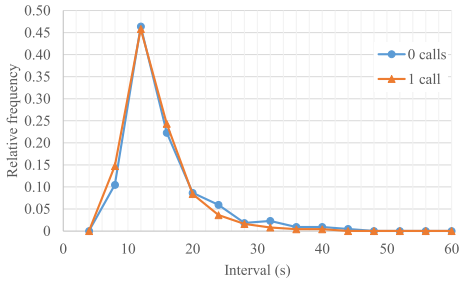
Fig. 14 Relative and cumulative relative frequencies of intervals (0 - 60 s).

Table 12 Average interval in assigned period.

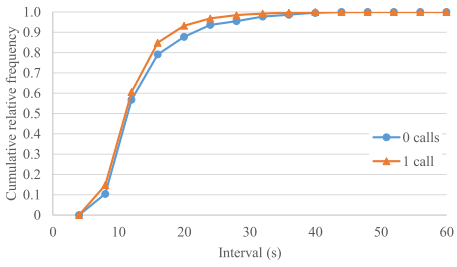
# of calls	10-min		30-min		60-min		90-min	
	Ave. (s)	Size	Ave. (s)	Size	Ave. (s)	Size	Ave. (s)	Size
0	13.4	220	22.4	5	-	0	-	0
1	12.4	251	13.4	283	17.9	36	-	0
2	-	0	10.9	85	13.6	168	25.1	28
3	-	0	-	0	10.4	220	19.1	112
4	-	0	-	0	10.5	35	12.1	130
5	-	0	-	0	-	0	9.0	3

RSR, and 90-min RSR and the conventional methods) from Fig. 14(b) between 12 and 28 s although the tests were divided into two groups of methods. The 90-min RSR method had the lowest CRF at the 12-24 s interval, and the 60-min RSR method had the highest CRF at the 12-28 s interval. Also, the medians of the 90- and 60-min RSR methods are the largest and smallest, respectively, and those of the other methods were the same in Table 10.

We observed a relation between the rate of the call attempts and the number of calls in the assigned period because time pressure might not only affect the call duration but also the rate of the call attempts. Table 12 shows the average interval between the call attempts and the sample size in the assigned period for each RSR method. The more calls in the assigned period, the shorter the average interval as shown in Table 12. The RFs and CRFs of 10-, 30-, 60-, and 90-min RSR methods are illustrated in Figs. 15 16, 17, and 18, where values for zero calls in the 30-min RSR method were included in those for one call and values for five calls

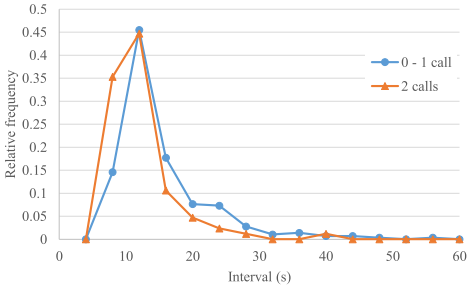


(a) Relative frequencies of intervals.

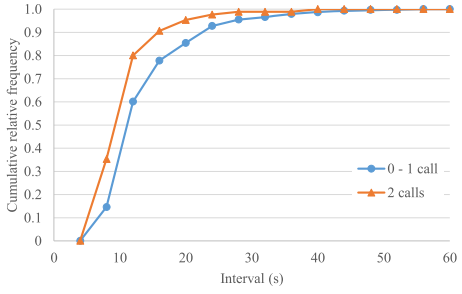


(b) Cumulative relative frequencies of intervals.

Fig. 15 Interval between repeated calls in 10-min RSR method.



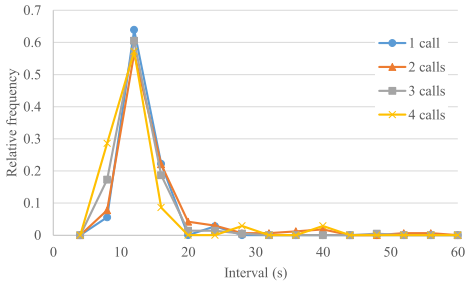
(a) Relative frequencies of intervals.



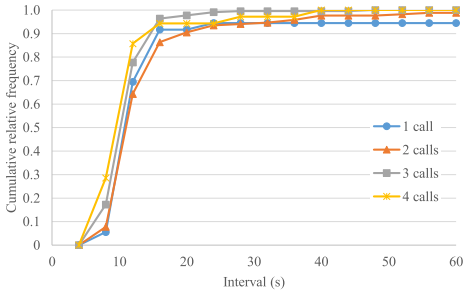
(b) Cumulative relative frequencies of intervals.

Fig. 16 Interval between adjoined call attempts in 30-min RSR method.

in the 90-min RSR method were included in those for four calls because of the small sample size. All RSR methods except the 90-min one had the same modes of the interval between the numbers of calls in the assigned periods although they had different averages. Only the 90-min RSR method had different modes of the interval between the numbers of calls. Calling parties for the 90-min RSR method seemed to

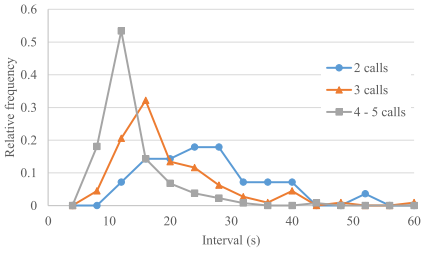


(a) Relative frequencies of intervals.

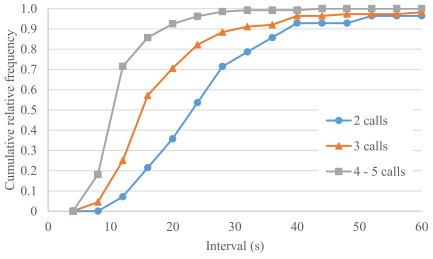


(b) Cumulative relative frequencies of intervals.

Fig. 17 Interval between adjoined call attempts in 60-min RSR method.



(a) Relative frequencies of intervals.



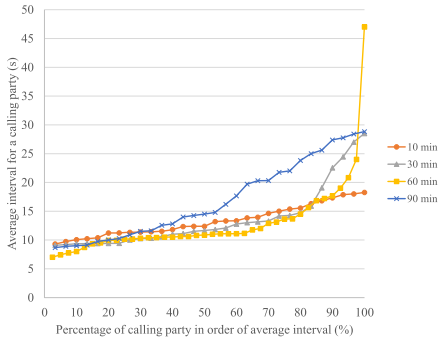
(b) Cumulative relative frequencies of intervals.

Fig. 18 Interval between adjoined call attempts in 90-min RSR method.

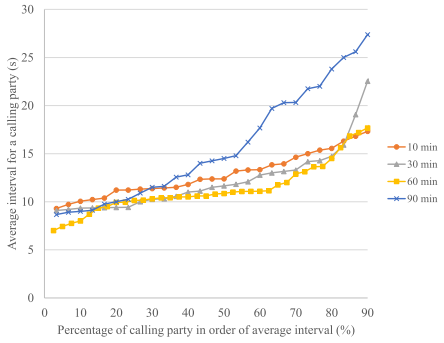
feel weaker time pressure when they tried to make calls than calling parties for other RSR methods.

5.3 Behavioral Analysis of Calling Parties

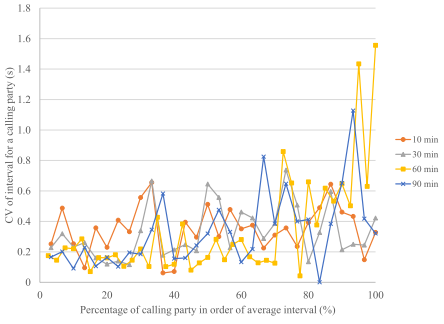
To understand how the assigned periods of RSR methods changed the rate of the call attempts by calling parties, we measured the average interval for each calling party and the CV for intervals of each calling party and arranged the



(a) Average interval.



(b) Average interval for 90 % calling parties



(c) CV.

Fig. 19 Average interval by calling party and CV.

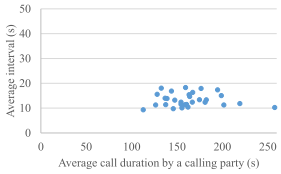
average intervals in ascending order as shown in Fig. 19 in the same manner as in Sect. 4.3. Intervals for the bottom 10% calling parties in the 60- and 90-min RSR methods varied widely because their CVs were larger than that in Fig. 19(c). Thus, we analyzed data of the average intervals for 90% calling parties in ascending order as shown in Fig. 19(b).

The lengths of the assigned periods for RSR methods changed average intervals from Fig. 19(b). A standard is required to compare the 10-, 30-, 60-, and 90-min RSR methods. Thus, we chose the average intervals of the 10-min RSR method as the standard for comparison because they were proportional to the ascending order of the average interval. They were proportional to it even in up to 100% as shown in Fig. 19(a) because the assigned period was short (60 s).

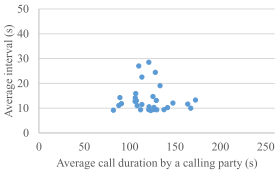
We compared others with those of the 10-min RSR method. The top 83% calling parties in the 30-min RSR method made more call attempts than those in the 10-min RSR method. The bottom 17% calling parties in the 30-min RSR method made fewer call attempts. Since their average interval increased suddenly, they seemed to give up making more calls because at most two calls were possible in the assigned period. The top 85% in the 60-min RSR method made more call attempts than those in the 10-min RSR method, and 85–90% made a similar number of call attempts. Moreover, the top 65% made many more call attempts because their average intervals hardly changed. Especially, the top 15% showed very short averages. Six minutes as the assigned period was effective to make most calling parties make more call attempts. Only the top 30% in the 90-min RSR method made more call attempts than those in the 10-min RSR method. The bottom 70% made fewer call attempts, and the bottom 25% made call attempts slowly and did not make more calls in their assigned period of nine minutes because their average interval increased at a high rate. Nine minutes as the assigned period was not effective to make most calling parties attempt more calls because nine minutes must have felt long as the limited period.

Table 13 Relationship between call duration and call attempt rate.

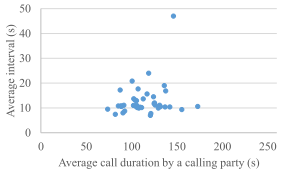
Method	Correlation coefficient
10-min	-0.04116
30-min	-0.07315
60-min	0.331937
90-min	0.211975



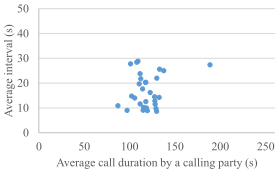
(a) 10-min RSR method.



(b) 30-min RSR method.



(c) 60-min RSR method.



(d) 90-min RSR method.

Fig. 20 Relationship between call duration and call attempt rate.

5.4 Rate of Call Attempts and Call Duration

The RSR methods except the 90-min one increased the rate of the call attempts as a side-effect of easing disaster congestion as shown in the previous subsections. If the side-effect depends on self-restraint to shorten call duration, the more effectively an RSR method shortens call duration, the larger its side-effect. Therefore, we analyzed the relationship be-

tween call duration and the rate of the call attempts by a calling party to investigate whether or not calling parties who had shorter call durations had higher rates of the call attempts. They were independent because correlation coefficients between the call duration and the rate of the call attempts for the 10-, 30-, 60-, and 90-min RSR methods were close to zero from Table 13. The outliers for the 60- and 90-min RSR methods caused the larger absolute values of the correlation coefficients for the 60- and 90-min RSR methods than those for 10- and 30-min RSR methods from Fig. 20.

6. Conclusion

We have investigated relations between calling parties' behavior and settings of the RSR method as one indirect control against disaster congestion. Clarifying the relation is valuable for the indirect control because the indirect control is directly connected to calling parties' behavior and the relation has not yet been investigated.

We revealed a relation between call duration due to callers' self-restraint and configurations of length of the regulated period for making calls. Our experiments found that the average call duration was the most effectively reduced by the 60-min road space rationing (RSR) method and second-most effectively by the 30- and 90-min RSR methods. The effect of the call duration reduction in the 10-min RSR method was the same as that in the conventional method. The reason the 60-min RSR was the most effective was that it was more effective for 60% calling parties and much more effective for 25% calling parties than the other RSR methods. We found that an average calling party can make 0.28 more calls per hour in the 60-min RSR method than in the 90-min one under the same call-blocking ratio assumption through the linear relationship between call duration and the number of calls in an assigned period. All calling parties were less self-restrained in the 90-min RSR method than in the 60-min one because the 90-min RSR method had a similarly shaped distribution of call duration to the 60-min RSR method but a larger peak of the distribution. The 30-min RSR method induced the same self-restraint in half of the calling parties who made two calls in the assigned period as the 60-min RSR method but weaker self-restraint in the other half who made one call in the assigned period because the shapes of the distribution for the two-call group and the 60-min RSR method matched, especially for short call durations. Calling parties in the one-call group seemed to give up making two or more calls.

Also, we found that the RSR methods except the 90-min one increased the rate of call attempts as a side-effect of easing disaster congestion, and the side-effect was at most a value between 1/8 and 1/7 when a group has 1/10 the users. The side-effects for the 10-, 30-, and 60-min RSR methods were almost the same. Calling parties in the 90-min RSR method and the conventional method attempted calls at the same rate even though the period in which to make a call was restricted for the 90-min RSR method but not for the conventional method. Nine minutes as the assigned period in the 90-min RSR method was not effective for making most calling parties attempt more calls because nine minutes must have felt long as the limited period. Most bottom calling parties in the 90-min RSR method made fewer call attempts, and the bottom 25% made call attempts slowly and did not make more calls in their assigned nine-min period. Although there were no statistically significant differences between the 10-, 30-, and 60-min RSR methods, the cumulative relative frequency (CRF) showed that there were two groups: 60-min, and 10- and 30-min. Most of the top calling parties in the 30-min RSR method made more call attempts than those in the 10-min RSR method. The rate of the call attempts of the 10-min RSR method was proportional to the ascending order of the rate of the call attempts. The other calling parties in the 30-min RSR method made fewer call attempts, and the rate slowed down suddenly. They seemed to give up making more calls because at most two calls were possible in the assigned period. Furthermore, we found that the side-effect was independent of the calling parties' self-restraint toward call duration.

Observing how the settings change calling parties' behavior is important because the reduction against disaster congestion directly depends on calling parties's behavior on the RSR method. We focus how the settings change call duration and call attempt rate of calling parties. Reduction of call duration is effectiveness and increase of call attempt rate is side-effect on the RSR method. Observing the change is essential to realize tge RSR method. However, the change has not yet observed because Satoh et al. [17] only observed one setting of the RSR method.

Congestion control based on callers' self-restraint can be used as a countermeasure against general congestion. Finding other applications is for further study.

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