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A passenger distribution analysis model for the perceived time of airplane boarding/deboarding, utilizing an ex-Gaussian distribution

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A B S T R A C T

This study focused on modeling the perceived time of boarding/deboarding. We conducted an experiment to understand how passengers in the study assessed boarding/deboarding times. According to the results of the analysis, the passenger distribution that took a ratio between perceived time and measured time as a variable was positively skewed. This distribution indicated that the proportion of the passengers for whom perceived time was longer than measured time varied depending on the experimental conditions. Based on this analysis, we have employed an ex-Gaussian distribution to develop a model. The model has revealed that the parameter τ, which expressed the length of the ex-Gaussian distribution tail, varied depending on the load factor, seat pitch, and boarding/deboarding methods. By changing these factors, it will be possible to shorten perceived time for certain passengers whose perceived time of boarding/deboarding is longer than measured time.

1. Introduction

Airplane movements at airports worldwide have been on an increasing trend lately, and airline companies are implementing various measures to reduce the time between flight arrival and departure to ensure timeliness. Within the flow of events from the time the airplane reaches the airport, the passengers disembark, the airplane's interior is cleaned and prepared, supplies are replenished, the next passengers board, to when the airplane departs again, boarding and deboarding take a long time, mainly because the passenger aisle is narrow and gets congested. Therefore, airline companies must reduce passenger boarding time for timely departure of flights. Consequently, airlines have developed various passenger boarding methods, such as boarding by row or giving priority boarding for passengers seated from back to front (Marelli et al., 1998; Van Landeghem and Beuselinck, 2002). Modifying the boarding time using boarding methods has been modeled in computer simulations in the past (Marelli et al., 1998; Van Landeghem and Beuselinck, 2002; Briel et al., 2003; Ferrari and Nagel, 2005; Bachmat et al., 2006; and Steffen, 2008). These methods have also been confirmed through experiments that used a mock-up of airplanes (Steffen, 2012). These studies confirm that the back-to-front boarding method does not necessarily minimize airplane boarding time.

On the other hand, in recent years, research related to perceived time is attracting attention in the field of travel behavior research. For example, a study on public transportation travel time found that the perceived time for traveling is longer for car drivers with regard to public transportation than the actual public transportation travel time, which explains why the modal shift from cars to public transportation has been difficult (Van Exel and Rietveld, 2010). Also, if the waiting time at the station was long, the perceived travel time of public transportation became longer, which again impacted the choice of public transport (González et al., 2015). Because the level of satisfaction greatly impacts airline selection, reducing actual boarding and deboarding times is critical for the airlines to increase passenger satisfaction. In addition to shortening the physical boarding time, shortening perceived time is also effective in improving passenger satisfaction.

This study focused on modeling the perceived time of boarding/deboarding, a topic presently unexplored in the literature. Moreover, it attempted to understand how passengers evaluate boarding and deboarding times, using an ex-Gaussian distribution enabled to determine the proportion of passengers whose perceived time was longer than the actual physical time it took for them to board and deboard. This will be useful in developing measures to improve passengers' level of satisfaction.

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2. Experiments

We conducted an experiment that compared perceived time with measured time, where the latter is the physical time taken to board and deboard. The experiment was conducted using tables and chairs placed in a room and were made to resemble the interior of an airplane. Participants acting as passengers were handed boarding passes and instructed to go to their allotted seats. A stopwatch was used to measure the duration from the time the first passenger entered the airplane to the time that the last passenger was seated, since this time is controllable by airline companies. A questionnaire was used to determine perceived time. The experimental conditions are summarized in Table 1. The experimental conditions of the load factor and the seat pitch differed for the low and high load factor experiments. Furthermore, two patterns were implemented for the boarding method: (1) a boarding pattern in which passengers entered the airplane in no predefined order (i.e., random boarding) regardless of the boarding passes held by them; and (2) a boarding pattern in which the seats were divided into front and back, and priority was given to passengers who were allocated seats at the back (block boarding) according to the boarding passes held by them. Two patterns were also used for deboarding: (1) a deboarding pattern in which passengers exit the airplane in no predefined order (i.e., random deboarding) regardless of the boarding passes held by them; and (2) a deboarding pattern in which deboarding started from the front (block deboarding) according to the boarding passes held by them. These boarding and deboarding patterns are shown in Fig. 1.

There are two methods for time estimation. One is prospective time estimation wherein assessment is performed in a situation in which it is already understood that time estimation will be conducted and the other is retrospective time estimation in which assessment of time is done afterward through recollection. In this study, passengers did not know that a time estimation survey will be conducted; the retrospective time estimation method was chosen.

The average value of perceived time, T_p, obtained from the experiment and measured time, T_m, are shown in Table 2.

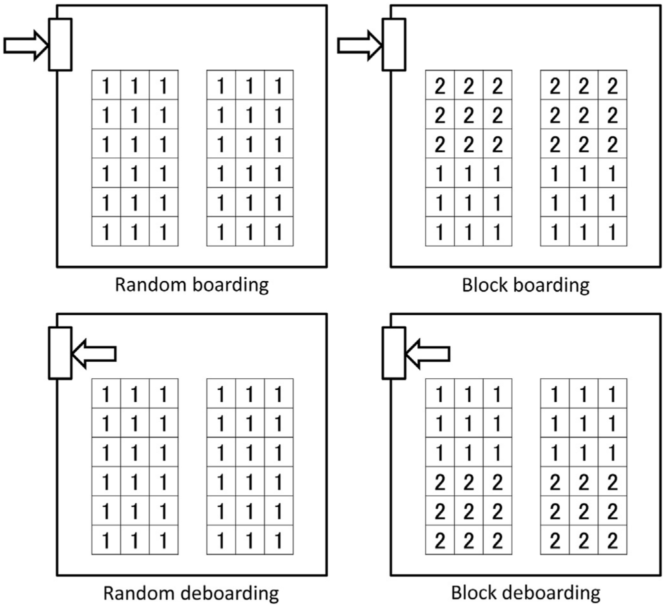

Fig. 1. Boarding and deboarding methods. *The order of boarding and deboarding is indicated by the numbers 1 and 2.

Comparing the averages for boarding, we see that $T_p < T_m$ for all conditions. For the high load factor, in particular, there is a huge difference between T_p and T_m compared to the low load factor. In the case of deboarding, we see $T_p > T_m$ for block deboarding and $T_p > T_m$ for the random deboarding for the low load factor, but $T_p < T_m$ for the high load factor.

The results of the experiments are also shown through a passenger distribution, taking the ratio of perceived time, T_p, and measured time, T_m, (T_p/T_m), as the variable. The passenger distribution was organized into the five cases of low load factor (Low L/F), high load factor (High L/F), and random boarding/deboarding

Table 1
Experimental conditions.

Name of Experiment	Low load factor	High load factor
Date	May 25, 2008	November 16, 2008
Number of Passengers (Number of participants in the experiment)	30 persons	36 persons
Passenger Attributes	Males and Females aged between 20 and 60	Males and Females aged between 20 and 60
Number of Seats	54 seats (9 rows × 6 columns)	36 seats (6 rows × 6 columns)
Load factor	55.6%	100%
Width of Aisle	80 cm	80 cm
Seat Pitch	85 cm	120 cm
Passenger Flow Rate	1 person every 4 s	
Boarding Method	Random boarding Block boarding in which seats were divided into front and back sections (back to front)	
Deboarding Method	Random deboarding Block deboarding in which seats were divided into front and back sections (front to back)	
Number of Experiments	One time each for random boarding and block boarding One time each for random deboarding and block deboarding	
Cautions during seating	To simulate the action of putting baggage in the overhead compartment, depending on the number of persons seated in the row in which one was to be seated, the passengers wrote their names several times. As the number of persons seated increased, the baggage in the overhead compartment also increased. To simulate the action of retrieving baggage, the passengers wrote their names once. Because the passengers already knew where their baggage were, the time required to retrieve the baggage was shorter than that to load the baggage. In this way, conditions related to the time required to load/retrieve the baggage were reproduced.	
Questionnaire	The questionnaire was distributed after the experiment was completed. The passengers reported the amount of time taken for the first passenger to enter the airplane to the time that the last passenger was seated, or the time taken for the first passenger to deboard to the time the last passenger deboarded (retrospective time estimation as per verbal estimation method was used.)	

Table 2
Results of the experiments, perceived time and measured time.

Name of the experiment	Boarding/Deboarding method	Average value of T_p	T_m
Low load factor	Random boarding	2:37:36	2:57:36
	Block boarding	2:25:00	2:49:54
	Random deboarding	0:42:30	0:39:40
	Block deboarding	1:10:32	0:41:00
High load factor	Random boarding	2:08:58	3:45:17
	Block boarding	2:03:03	4:03:59
	Random deboarding	0:15:43	0:40:19
	Block deboarding	1:05:14	0:41:26

(Random), block boarding/deboarding (Block), and entire sample (All). The statistical values for each are summarized in Table 3. Further, to confirm the number of samples that could withstand the analysis, samples were taken for the four patterns of random boarding/deboarding and block boarding/deboarding for both the low and high load factors. In addition, for random boarding/deboarding, samples were taken for the four patterns of random boarding/deboarding for the low and the high load factors. In the case of block boarding/deboarding, samples were taken for the four patterns of block boarding/deboarding for the low and the high load factors.

Upon comparison of load factors, we find that the average value is greater than 1 for Low L/F but is below 1 for High L/F. Further, the passenger proportion of $T_p/T_m > 1$ is 59.7% for Low L/F, whereas it is 27.2% for High L/F. This shows that, for Low L/F, a greater number of passengers felt that perceived time was longer than measured time.

Upon comparison of boarding/deboarding patterns, we find that the average value is below 1 for Random but is greater than 1 for Block. Moreover, the passenger proportion of $T_p/T_m > 1$ is 35.8% for Random and 46.1% for Block. This shows that for Block, a greater number of passengers felt that perceived time was longer than measured time.

The passenger distributions are shown in Fig. 2. Here to compare each case, the area of the histogram is normalized to equal 1.

3. The model

In Fig. 2, the passenger distribution that takes T_p/T_m as the variable is positively skewed. With respect to constructing the passenger distribution model, positively skewed distributions, such as a log-normal distribution, an ex-Gaussian distribution, a Weibull distribution, and a Gumbel distribution, are considered appropriate. As is clear from the results of the experiment, there is a difference with respect to the proportion of $T_p/T_m > 1$ for each case. Therefore, formulating a model using an ex-Gaussian distribution that includes the parameter (τ) can be considered appropriate for expressing the length of the distribution tail. The ex-Gaussian distribution is generated by the convolution of normal and exponential distributions and has three parameters, μ, σ, and τ. μ represents the peak of the distribution, σ expresses the variance around the peak, and τ represents the length of the distribution tail.

Table 3
Results of experiments, statistical value of passenger distributions.

	Low L/F	High L/F	Random	Block	All
Number of Samples	77	92	67	102	169
Minimum Value	0.24	0.12	0.12	0.13	0.12
Average Value	1.22	0.91	0.90	1.15	1.05
Maximum Value	5.12	4.34	3.61	5.12	5.12
Standard Deviation	0.86	0.83	0.67	0.95	0.86
Proportion of $T_p/T_m > 1$	59.7%	27.2%	35.8%	46.1%	42.0%

The probability density function of the ex-Gaussian is given by equation (1).

$$f(x|\mu,\sigma,\tau) = \frac{1}{\tau\sqrt{2\pi}}\exp\left(\frac{\sigma^2}{2\tau^2} - \frac{x-\mu}{\tau}\right)\cdot\int_{-\infty}^{\frac{x-\mu}{\sigma}-\frac{\sigma}{\tau}}\exp\left(-\frac{y^2}{2}dy\right) \qquad (1)$$

To construct a model of the five cases of Low L/F, High L/F, Random, Block, and All, the maximum likelihood estimators were used to estimate the parameters (μ, σ, τ) of the ex-Gaussian distribution from the data of each case (Cousineau et al., 2004). The parameters of the ex-Gaussian distribution are shown in Table 4. The p-value shown in Table 4 is as per the Kolmogorov–Smirnov test, which indicates the probability of a match of the shape of the experimental value distribution and the ex-Gaussian distribution. Where the significance level is below 5%, the two distributions are not considered to have the same shape. In either case, the p-value is not below the 5% significance level and the coefficient of determination is 0.95 or more; thus, it was possible to apply the passenger distribution with T_p/T_m as the variable to the ex-Gaussian distribution.

Fig. 3 shows a histogram of All wherein the area of the experimental value becomes 1 as well as the curve of All that expresses an ex-Gaussian distribution, which is fitted by performing the parameter estimation through the use of maximum likelihood estimators.

With respect to the five model parameters, the μ parameter expressing the peak position is in the proximity of 0.2. In the case of boarding and deboarding from the airplane,—approximately one to five minutes on the time scale—the majority of passengers felt perceived time to be approximately 1/5 of measured time. In addition, the retrospective time estimation was used in this experiment. It tended to be a shorter perceived time rather than the prospective time estimation (Block, 1992). If Low L/F is excluded, the σ parameter, which expresses variance in the proximity of the peak position, becomes approximately 0.06–0.07, and no significant difference exists between the models. When Low L/F and High L/F are compared for the τ parameter that expresses the length of the tail, Low L/F becomes longer, showing that the majority of passengers felt perceived time to be longer than measured time in the experiment results. Comparing Random with Block, Block takes longer and is the same as the experiment results. Thus, differences in the load factor and seat pitch that constituted the differences in the conditions of Low L/F and High L/F, and boarding/deboarding methods can be considered as the factors to change τ.

4. Discussion

In the field of experimental psychology, time perception refers to the time interval that is estimated by one's own perception. Numerous studies have been conducted in this field, and several models have been constructed and proposed on the basis of the experimental results. For example, in the change model, a participant's internal clock changes depending on their metabolism (Hoagland, 1933, 1981); in the storage size model, perceived time changes depending on the amount of information stored in the participant's memory (Ornstein, 1969); and in the attention model, perceived time changes depending on the attention distribution for the time and the non-time information processing systems (Thomas and Canter, 1975, 1976; Thomas and Weaver, 1975). There is also the four multiplicative factor model (Matsuda, 1996), which is given by equation (2); this model is an integration of the aforementioned models. In this model, the duration of perceived time (T) can be expressed by multiplying 1) elapsed time (t) with 2) the frequency of the tempo of the internal clock (f), 3) the extent to

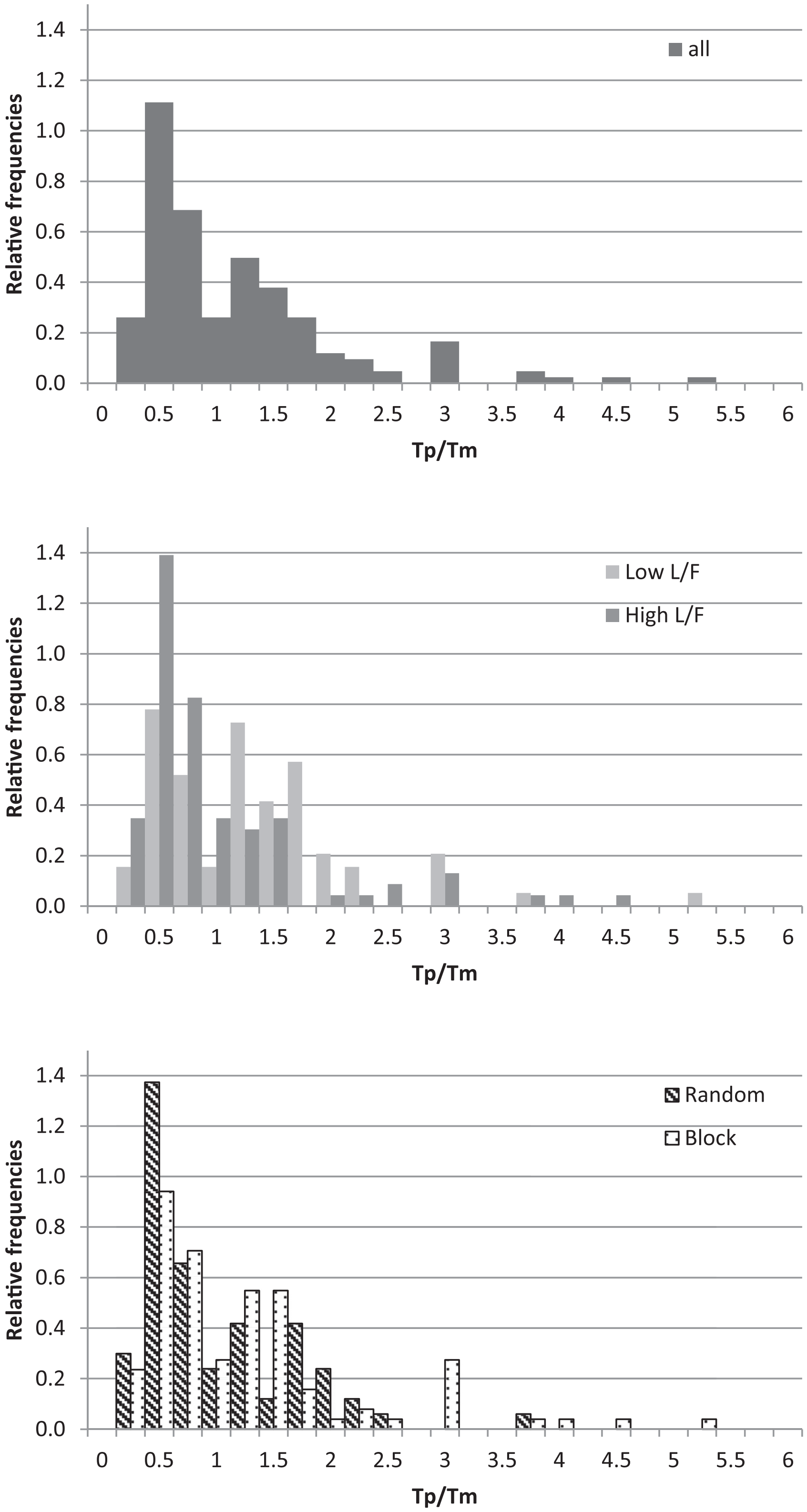

Fig. 2. Passenger distributions of the ratio of perceived time to measured time.

Table 4
Results of the parameter estimation.

	Low L/F	High L/F	Random	Block	All
μ	0.244	0.215	0.217	0.221	0.217
σ	0.248×10^{-4}	0.073	0.061	0.062	0.060
τ	0.974	0.693	0.682	0.928	0.833
P Value (KS Test)	0.155	0.136	0.355	0.593	0.365
Coefficient of determination	0.951	0.964	0.953	0.979	0.991

Table 5
Experiment results, average value of $f\cdot a\cdot b$.

Name of experiment	Boarding/Deboarding method	Average value of $f\cdot a\cdot b$
Low load factor	Random boarding	1.07
	Block boarding	1.03
	Random deboarding	1.07
	Block deboarding	1.72
High load factor	Random boarding	0.83
	Block boarding	0.67
	Random deboarding	0.39
	Block deboarding	1.57

which attention is focused on the lapse of time (a), and 4) the degree that the awareness of attributes other than those of time among the events during the elapsed time influences perceived time (b).

$$T = f\cdot a\cdot t\cdot b \text{ however}, \ f>0, \ \ 0<a\le 1, \ \ t>0, \ \ b>0 \tag{2}$$

T: The duration of perceived time expressed in relation to the regular time unit [hours: minutes: seconds]

f: The frequency of the tempo of the internal clock; it is high if one is in a neuro-physiologically tense situation and low if in a situation of restraint.

a: The ratio of attention focused on the elapsed time; it takes a value between 0 and 1.

t: Elapsed time that can be physically measured [hours: minutes: seconds].

b: The degree of influence on perceived time by the awareness of the attributes, other than those of time, from among the types of stimulations one is exposed to during the elapsed time.

Each of the factors f, a, and b can be considered as having parts determined by the experimental conditions and by individuals. The factor f represents the frequency, depending on the neuro-physiologically tense situation. In the controlled experimental conditions of this study, it is a rather restrained situation. The factor a represents the ratio of focusing attention on the elapsed time in this study; when conducting the retrospective time estimation, the ratio of focusing attention on the elapsed time has a low tendency. The factor b represents the influence of stimulation, other than time, on perceived time and can be considered as corresponding to the load factor, seat pitch, and boarding/deboarding method, the factors that change the τ parameter.

The $T/t = f\cdot a\cdot b$ is calculated for each passenger from the experimental results and the average value is shown in Table 5. In the case of the experiment being conducted for the same passenger on the same day, if f and a are supposed to be constant, the difference due to boarding method is expressed in b, the magnitude correlation of $f\cdot a\cdot b$ can be considered as corresponding to the magnitude correlation of b. For both the low and high load factor experiments, the value of $f\cdot a\cdot b$ becomes random boarding > block boarding in the case of boarding and becomes random deboarding < block deboarding in the case of deboarding. In the case of boarding, the time it took for passengers to line up was less for block boarding than for random boarding, and there was a tendency for perceived time to become shorter. On the other hand, when deboarding randomly, a passenger could deboard in the order in which passengers had lined up. However, in the case of block deboarding, there were always passengers who had to wait; thus, there was a tendency for perceived time to become longer. Further, as passengers differ in the low and high load factor experiments, it can be estimated that the numerical value of f and a will differ. However, as the passengers were randomly selected, if one supposes the average value to be equal, then the value of $f\cdot a\cdot b$ becomes low load factor > high load factor. If the load factor was high when boarding, it was estimated that certain passengers (especially passengers boarding later) expected that boarding will take more time, and hence there was a tendency for perceived time to become short. In addition, in the low and high load factor experiments, the seat pitch differed. In the case of the low load factor experiment in which the seat pitch was narrow, it was difficult for the passengers to move and boarding and deboarding took longer; hence, there was a tendency for perceived time to be longer.

With regard to the boarding/deboarding method, there is a possibility that the way perceived time is experienced differs between boarding and deboarding. In this study, the boarding and deboarding samples were totaled to confirm the samples needed to create the passenger distribution, and it was not clear whether Random or Block shortened the τ parameter during boarding and deboarding times.

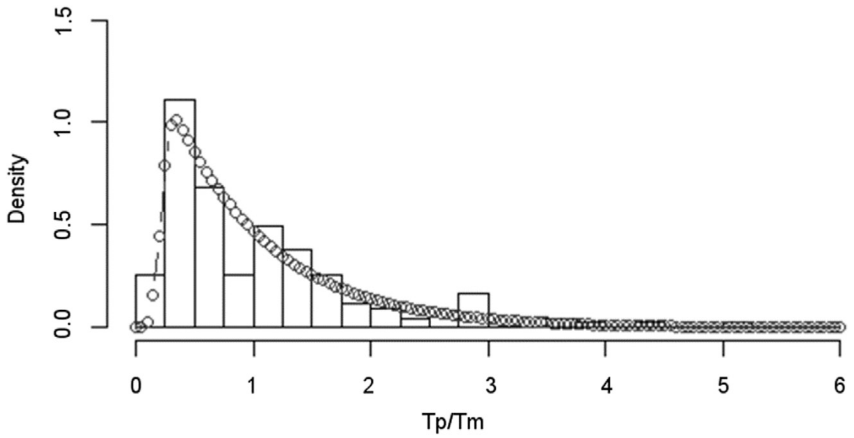

Fig. 3. Experimental value of passenger distribution and the ex-Gaussian distribution fit (all).

Collecting sufficient samples and recreating the experiment to make a passenger distribution is important in the future.

Finally, the airlines can control the load factor, seat pitch, and boarding/deboarding methods, which impact the influence of the range of the passenger distribution related to perceived time. Hence, depending on the measures taken by the airlines, it will be possible to reduce the number of passengers for whom perceived time is longer than physical time.

5. Conclusion

This study showed that in airplane boarding and deboarding, the proportion of passengers for whom perceived time was longer than measured time can be expressed through the τ parameter of an ex-Gaussian distribution. This is possible by modeling passenger distribution using an ex-Gaussian distribution with the ratio of perceived time and measured time taken as the variable. Further, differences in the load factor, seat pitch, and boarding/deboarding methods are considered as the factors to change parameter τ.

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