Journal of Information Processing Vol.20 No.2 508–511 (Apr. 2012)

[DOI: 10.2197/ipsjjip.20.508]

Regular Paper

A Decision Making Model and Its Application to Airplane Accidents

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Received: February 10, 2011, Accepted: December 16, 2011

Abstract: A simple formula of a decision making process is introduced and applied to airplane accidents: a near-miss case of Douglas DC-10-40 with Boeing 747-400D in 2001 and a collision between Tupolev 154M and Boeing 757-200 cargo jet in 2002. The decision making process is shown as the plot of $lnln(1 - y)^{-1}$ versus lnt with phase-change ratio, y and time, t and thus, it shows the diffusion law when the plot is linear. The flight data focused on altitude from cruising to descending is applied to the model and a clear phase-change is demonstrated. The timing of the phase-change means the "decision making" point and is estimated as timing for pilots to start to perform maneuvers. This model may be applied to a large number of cases related to the human factors on decision making.

Keywords: decision making, phase-change, diffusion law, airplane accidents, Traffic Alert and Collision Avoidance System (TCAS)

1. Introduction

Boeing 747-400D (Boeing 747) and Douglas DC-10-40 (DC 10) belonged to Japan Airlines were involved in a near-miss at 36,000 feet high over Japan on January, 31st., 2001 [1], [2]. Boeing 747 ascending to the final cruising flight level of 39,000 feet (FL390) from Tokyo International Airport to the west, was instructed to descend to FL350 by the air traffic controllers (ATC). DC-10, cruising at FL370 from Pusan, Korea to the east, was descending by the instruction of Traffic Alert and Collision Avoidance System (TCAS). Just before being the crossing, Boeing 747 dove sharply causing injuries to many passengers and crew members.

Tupolev 154M, en route from Moscow to Barcelona collided in mid air with Boeing 757-200 cargo jet (Boeing 757) cruising from Italy to Brussels, Belgium over Germany on 1st of July, 2002, killing all passengers and crew of both airplanes [3]. Tupolev 154M descended by the ATC instruction although it received the instruction to ascend by TCAS just two seconds after. Boeing 757 also descended by the instruction of TCAS.

Particular concerns are considered to be human and system errors. That is, for one, the ATC gave a wrong instruction to Boeing 747 [4] and the pilots dominated ATC's instruction to the TCAS to ascend in the former case [2]. Pilots on Tupolev 154M couldn't obey the instruction of TCAS to ascend [3], in other words, they couldn't change their mind to descend instructed by the ATC. The other, the system in the air traffic control was not perfect to the human factor error, neither. TCAS system was not effective for the accidents based on human factor error mentioned above. There, even though ATC side, was no information support to know how pilots change their flight level and when at that time [2].

The system, an algorithm of TCAS, was improved to be changeable depending on the both traffic shortly afterwards the accident in Europe [5]. There is, however, an intrinsic problem related to the possibility of human factor errors still remains: no one knows when and how pilots decide to change their flight level if there is no an explicit statement from pilots themselves.

There is not so much research about decision making based on human factor [6], [7]. Thus, a simple and effective model for forecasting phenomena is required.

In this paper, at first, a decision making model using a simple diffusion law is introduced and applied to the airplane accidents mentioned above. Second, the timings and behavior of the decision making based on the flight data are shown quantitatively.

2. Modeling and Method

What happens in brain when people get an idea or change mind? According to a primitive explanation, it is considered that physiological impulse based on physical stimuli into the brain starts to rush and decreases with increasing time. In other words, a quasi stable state with some concentration of the impulse shifts to another state with different value of concentration after getting an idea or changing mind, as illustrated in **Fig. 1**. At the time, we think an idea has been born or a decision has been made (hereafter, we say that the trigger of getting an idea/mind as a 'decision making'). The decision making process is described by the conventional diffusion law [6], [7]. Applying the analogy from diffusion law in solid [8] [*1], the decision making is described as Eq. (1) in a linear system,

$$-dC(t)/dt = \kappa C(t). \quad (1)$$

*1 Reference [8] notes "while the statement of the law of diffusion is often adequate, it must be pointed out that it is shown in thermodynamics that the gradient of the chemical potential is rigorously the driving force for diffusion and not the concentration gradient alone."

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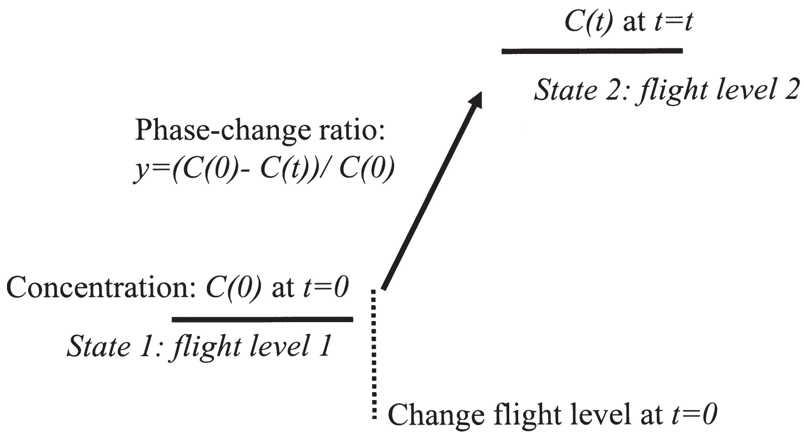

Fig. 1 Illustrated decision making model.

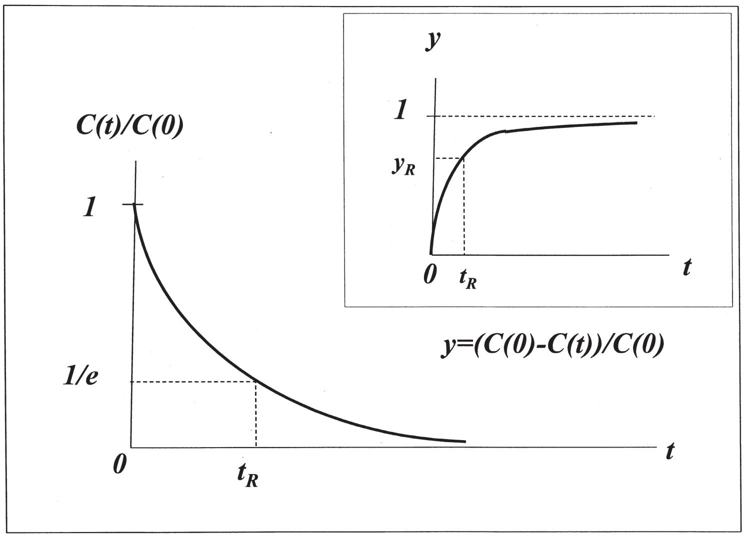

Fig. 2 Schematic model of decision making: time dependence of the concentration, $C(t)$ and phase-change ratio, y.

Here, $C(t)$ is the concentration which shows the density of the impulse at time t. κ is a diffusion coefficient showing as $\kappa = \nu_0 \cdot \exp[-Ea/(k_B T)]$. ν_0 is a frequent factor, Ea is an activation energy, k_B is the Boltzmann constant, and T is a reaction temperature. The diffusion coefficient, κ, which has a dimension of square meter per second in MKS unit, is defined with changing variant of x in original formula to time, t. Equation (1) shows that the concentration of the impulse depends on time, t when other parameters are independent on time. Time dependence of normalized concentration, $C(t)/C(0)$ is schematically shown in **Fig. 2**. $C(t)$ and $C(0)$ are the concentration of the impulse at the time, $t = t$, and $t = 0$, respectively, as shown in Fig. 1. A decision is triggered at $t = 0$ in this model. As the phase-change ratio, y is defined as $y = (C(0) - C(t))/C(0)$, y is led to Eq. (2) after integrating Eq. (1) with the condition of $C(0)$ and $C(t)$ at $t = 0$ and $t = t$.

$$y = 1 - \exp[-(\kappa t)^n] \tag{2}$$

Here, n, a reaction coefficient in the kinetics of solid, is newly defined for the empirical equation in the present model. y is also shown in inside figure of Fig. 2. By integrating Eq. (2), we deduce Eq. (3) as,

$$ln\, ln\, (1 - y)^{-1} = n\, lnt + const. \tag{3}$$

The physical parameters in solid mentioned above are included the constant term of the equation as they are independent on time in this model [9].

Equations (2) and (3) are the same empirical formula which is well known as a Johnson-Male's equation for describing kinetics in metal [10], [11]. When the data plotted as $lnln(1 - y)^{-1}$ versus lnt is linear, it leads the diffusion law with reaction coefficient, n, which is the slope of the line. The value of n is thought to show an acceleration in the decision making.

How do people make a decision? Thinking of a simple case, when pilots of airplane will change mind from the altitude of cruising to up/down by instruction or by their desire, impulse in brain with a quasi stable state (cruising) is triggered at $t = 0$ to be up/down and it diffuses with increasing time, as shown in Fig. 1. Assuming the concentration to be the flight level ("*State*1: *flight level* 1" and "*State*2: *flight level* 2" as shown in Fig. 1), the phase-change ratio, y is schematically shown as an insert figure of Fig. 2. Relaxation time, t_R is sometimes defined as a value of $1/e$ of initial value. The relaxation was led as a time of recognition complete in the psychological experiment [7], in which the

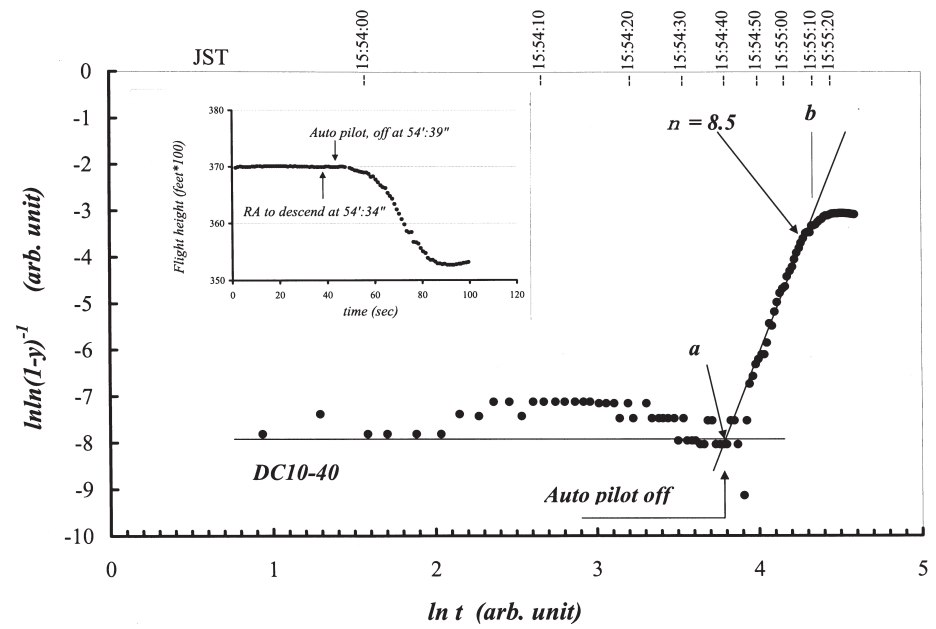

Fig. 3 Flight locus and $lnln(1-y)^{-1}$ versus lnt plot for DC-10. Insert figure shows the altitude versus time in Ref. [2]. Time "0" indicates 15:53':55" in JST. DC-10 cruising at FL 370 started to maneuver to descend at 15:54'39" ('arrow' in the figure with indication of "auto pilot off") after the instruction of RA at 15:54':34". The $lnln(1-y)^{-1}$ versus lnt plot shows a phase change at "a" indicated in the figure. "b" in the figure is the time when both airplanes crossed each other at 15:54':11" in JST. The figure was made by modifying after Ref. [6] by the author.

several images from coarse to fine were shown to examiners and the rate of right answer was tested.

Flight data was referred from the references for the DC-10 [2] and that for Tupolev 154M and Boeing 757 [3]. We used the altitude data and time for applying to this model. The timing was referred in Japan Standard Time (JST) for the former case and Universal Standard Time (UTC) for the latter. Altitude is shown as the flight level (FL).

3. Result and Discussion

Three simple locus of DC-10, Tupolev 154M and Boeing 757, in two airplane accidents are applied to confirm this decision making model. Flight locus and the $lnln(1-y)^{-1}$ versus lnt plot of DC-10 is shown in **Fig. 3**. Insert figure shows the locus of real time scale. Timing "0" indicates 15:53':55" in JST. DC-10 cruising at FL 370 started to maneuver to descend at 15:54':39" ('arrow' in the figure with "auto pilot off") by the instruction of RA at 15:54':34". DC-10 descended after several seconds because of its inertia.

The phase-change from cruising to descending is shown using the $lnln(1-y)^{-1}$ versus lnt plot of the locus. First of all, the linearity of the two phases, cruising (slope $n = 0$) and descending (slope $n = 8.5$) are clearly shown. Second, the cross point of the slopes at about 15:54':40" means the "decision making" in the model. The cross point (indicates a in the figure) corresponds to the timing of the maneuver of the "auto pilot off" done by the pilots in DC-10.

Figure 4 shows the collision case between Tupolev 154M (◇) and Boeing 757 (●) in 2002. In the figure, both airplanes' locus and the $lnln(1-y)^{-1}$ versus lnt plot are superimposed because of the numerical simplification by the report [3]. Time dependence of the flight levels are shown in insert figure. The timing "0" indicates 21:34':30" in UTC. Cruising at the same flight level (FL 360), they received the RA at the same time at 21:34':56": to ascend for Tupolev 154M and to descend for Boeing 757. Two seconds prior to the RA-ascend, Tupolev 154M initiated to descend according to the instruction by ATC [3].

As shown in the figure, the $lnln(1-y)^{-1}$ versus lnt plot are linear and the cross point is clear. The cross point means a timing of the "decision making" and corresponds to the timing of the "RA instruction" at 21:34':56". They collided at 21:35':32", although additional TCAS were issued to avoid the collision as RA increase (increase descend) for Boeing 757 and increase RA to ascend for Tupolev 154M at 21:35':10" and 21:35':24", respectively. The simulation for the additional RA-increase is not clear because of small number of data [3]. Here, as the value of n is to show an acceleration of the decision making mentioned above, it is important to compare the difference of the slope of the $lnln(1-y)^{-1}$ versus lnt plot for related airplane locus. However, it is not appropriate to compare the slope directly with difference figures because of different factors/conditions for evaluation.

In summarizing the decision making process is analyzed and confirmed for the case of airplane locus to ascend/descend from cruising state. The $lnln(1-y)^{-1}$ versus lnt plot shows a clear decision making process: from linear line to another line with different slope values. The cross point of the slopes is the "decision making" in the model. The points correspond to the timing when the pilots start maneuver to descend in these flight locus based on the TCAS instruction.

By examining the flight altitude data using the simple diffusion model in mind, the timings of decision making were estimated quantitatively.

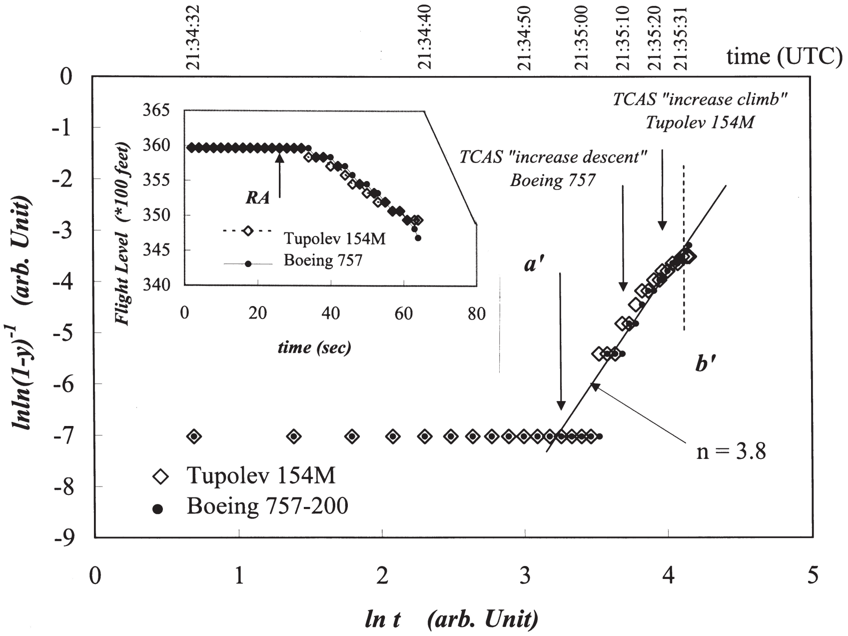

Fig. 4 Flight locus and the $lnln(1 - y)^{-1}$ versus lnt plot for Tupolev 154M and Boeing 757. Insert figure indicates the time dependence of flight level [3]. Time "0" is at 21:34':30" in UTC. The phase change indicated as "a'" shows the 'decision making', corresponds to the timing of RA for both airplanes. "b'" indicates the time of collision at 21:35':32". The figure was made by modifying after Ref. [6] by the author.

4. Conclusion

A simple formula for the decision making process is introduced and applied to the airplane accidents: a near-miss case of DC-10 with Boeing 747 in 2001 and a collision between Tupolev 154M and Boeing 757 in 2002. The decision making process is shown as the plot of $lnln(1 - y)^{-1}$ versus lnt with phase-change ratio, y and time, t and thus, it leads the diffusion law when the plot is linear. Flight data focused on altitude from cruising to descend was examined and was demonstrated as time of the "decision making". This model may be applied to a large number of cases related to the human factors on decision making.

Acknowledgments The author would like to express his thanks to Mr. Masahiro Ito for introducing me LaTeX.

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