Research Article

Relationship between Occupant Characteristics, Building Characteristics, and Pre-Fire Evacuation Time in Medium Plastic Industries in Thailand

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Abstract

An evaluation of Required Safe Egress Time (RSET) is a crucial step in performance based on fire safety engineering design. Moreover, pre-evacuation time is also essential for RSET. Consequently, pre-evacuation time is regarded as key aspects of evacuation process. The purpose of this cross-sectional study was to determine factors related to pre-evacuation time. Subjects were 375 workers among ten medium plastic industries. Data were collected by using a standardized occupant characteristics questionnaire, building characteristics survey and standardized observation form. Pearson's correlation, ANOVA and Regression analysis were performed in the analysis. The findings revealed several factors significantly associated with pre-evacuation time ($P<0.05$). Those factors are number of building floors, building age, number of windows, number of fire exit doors, distance from work station to fire exit door, width of fire exit door. The occupant characteristics were also associated with pre-evacuation time, which are not participated in fire exercise and occupant attitude. Regression analysis covers eight affected variables from those analysis. Only four influenced variables consisted of occupant attitude in fire, number of fire exit door, no fire training participation, and distance from work station to fire exit door were tested by using regression analysis. A multiple regression model was run to predict pre-evacuation time from four influenced variables. These variables statistically significantly predicted pre-evacuation time, the regression model is a good fit of the data. These are crucial factors to determine pre-evacuation time in further research.

Keywords: Pre-evacuation time; Building characteristics; Occupant characteristics; medium plastic industries

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1. Introduction

Saving human life is the ultimate goal in fire protection processes. A proper fire evacuation plan is necessary to obtain this goal. Two methods should be considered [1]. Firstly, prescriptive method which deals with the size and number of exits, density of people together with the length and width of evacuation routes. Secondly, performance method which deals with the maximum time for evacuation. The performance method depends on the definition and comparison between an Available Safe Egress Time (ASET), the time at which tenability criteria are exceeded because of smoke, toxic effluents and heat in a specific space and Required Safe Egress Time (RSET), it is the escape time. The universal criteria of safe fire evacuation timeline is shown in Figure 1 [2]. An evaluation of RSET is a crucial step in performance based on fire safety engineering design. Pre-evacuation time is also essential for RSET. Pre-evacuation time is considered as a major component of occupant evacuation time. The findings of research by Bryan, J.L., Fahy, R.F. and Proulx, G.[3, 4, 5] have suggested it is the most crucial element of RSET. Moreover, it is measured since an alarm goes off until the time that occupants are ready to evacuate toward a safe place [6].

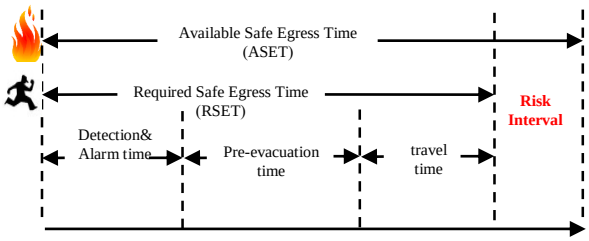

Figure 1. Universal criterion of safe fire evacuation timeline.

Consequently, pre-evacuation time is presently regarded as key aspects of evacuation process. The pre-evacuation needs to be explicit in order to save building evacuees. The studies revealed three critical factors for determining the degree of fire response performance. Those factors are fire characteristics, occupant characteristics, and building characteristics [7]. Furthermore these three factors associated to each other; which were found to be scarce [8].

The nature of fire influent response performance after the ignition and generating heat, smoke yield and toxicity which is uncontrollable. The building characteristics show physically surroundings and people's activities. The last factor which is occupant characteristics. Finally, occupant characteristics are varied from the individual knowledge, prior fire evacuation training and fire experience, fire attitude.

Therefore, this study attempted to focus on the features of each factor and study the relationship between occupant, building characteristics and pre-evacuation time in the medium plastic industries (50-200 workers) in Thailand which does not considered the fire characteristics as the result of uncontrollable factors.

2. Materials and Methods

2.1 Study design and setting

A cross section study was conducted in January - April 2015 at ten medium plastic industries in Thailand. The 375 workers from ten medium plastic industries were unaware of being observed by an assigned observer in each company. These subjects were identified by Krejcie, R.V. and Morgan, D.W. [9].

2.2 Instrument development

An instrument for data collecting consists of occupant characteristics questionnaire, building characteristics survey, pre-evacuation behavior and pre-evacuation time observation form. All collecting form was verified the Index of Consistency (IOC) by five fire specialist. There were three forms for collecting the data. Three forms of the study is described below.

2.2.1 Occupant characteristics questionnaire consists of three sections as below.

- Individual data of 375 workers was asked to do self-administered questionnaire. There were asked about sex, age, education level, marital status, income, work experience, section, position, physical condition, working building floor, fire experience, fire training participation, fire drill participation, using fire prevention and suppression devices, and fire prevention and suppression plan. All questions were multiple choice and filled in the blank.
- Knowledge about fire prevention and suppression questions consisted of 17 items. All items were binary choice (Yes or No). Cronbach's Alpha Coefficient was used for reliability analysis which was 0.611. If Cronbach's Alpha Coefficient greater than 0.6 is considered acceptable [10].
- Occupant attitude in fire questions consisted of 25 items. All items were Likert Scale [11]. Also, Cronbach's Alpha Coefficient was used for reliability analysis which was 0.880. If Cronbach's Alpha Coefficient greater than 0.8 is a good reliability [10].

2.2.1 Building characteristics survey

Building characteristics were surveyed by researchers which consisted of plant lay out, fire alarm type, number of building floor, building age, distance from work station to fire exit door, occupant density, width of corridor, number of exit access, width of exit access, height of exit access, number of window, width of window, height of window, number of fire exit door, width of fire exit door, height of fire exit door, fire exit door characteristics, fire resistance exit door, fire wall resistance, and fire prevention and suppression devices installation.

2.2.3 Pre-evacuation behavior observation form consisted of two sections. The first section contained questions that identified pre-evacuation behaviors: (1) notifying others, (2) fire investigation, (3) calling fire brigade, (4) ignore, (5) collect their belongings, (6) calling others, (7) close/open doors or windows, (8) shut down machine, (9) rescue others, (10) cover their nose with wet cloth, (11) ring an internal emergency response team (ERT), (12) grasping fire extinguishers to put out fire, (13) fire hose to put out the fire, (14) repress the fire alarm bell, (15) call 191 or 199, (16) immediately fire evacuation to the fire exits, (17) seeing at the others, (18) asking the others, (19) Thought it was alarm test and (20) thought it was false alarm. The second section of the observation form consists of the observation of pre-evacuation time which was transformed from pre-evacuation behaviors toward pre-evacuation time.

2.3 Data analysis

An occupant characteristics, building characteristics, and pre-evacuation observation form were administrated among workers in ten medium plastic industries of Thailand after the fire alarm went off and they were unaware of being observed. Out of 487 workers, 375 workers were observed (response rate of 88.86%). Descriptive analysis was used to describe characteristic of study subjects, sex, age, education level, marital status, income, work experience, section, position, physical condition, working building floor, fire experience, fire training participation, fire drill participation, using fire prevention and suppression devices, and fire prevention and suppression plan. Pearson's correlation coefficient, ANOVA, regression analysis at level of confidence 95% are well known statistical approaches used to study the relationship between occupant characteristics, building characteristics, and pre-evacuation time in fire of medium plastic industries.

3. Results

The fire response performances of occupants in the building fire consisted of three factors. These factors are presented, per characteristics, in Figure 2.

3.1 Occupant characteristics

The study occupant characteristics consisted of 375 workers aged between 17-56 years who had been working in the medium

plastic industries in Thailand which had a fire prevention and suppression plan (98.4%). The study occupant consisted mainly of female (69.6%) and the most of them had been working on the first floor (78.4%) and had been working in the factory less than four years (51.7%) in the position of staff(91.5%) at production section (71.2%), the education level of workers were secondary education level (65.9%), marital status is single (54.9%) as well as physical condition is not disable (98.7%), income of workers are between 5,000-10,000 Baht (50.4%, $\bar{x}$ = 12,661.98, S.D.=5, 986.58), the workers never went through the fire experience (82.9%) but have attended fire training, fire drill participation which were 84.0% and 90.9% respectively and they can use fire prevention and suppression devices properly, knowledge and occupant attitude in fire of workers were considered the criteria of Bloom [12] for interpreting the results. It was found that the knowledge about fire prevention and suppression of workers were neutral knowledge level (52.5%, $\bar{x}$ = 12.96, S.D.=1.66), and occupant attitude in fire of workers were not concern attitude(74.4%, $\bar{x}$ = 67.05, S.D.=11.23). The characteristic of participants are shown in Table 1.

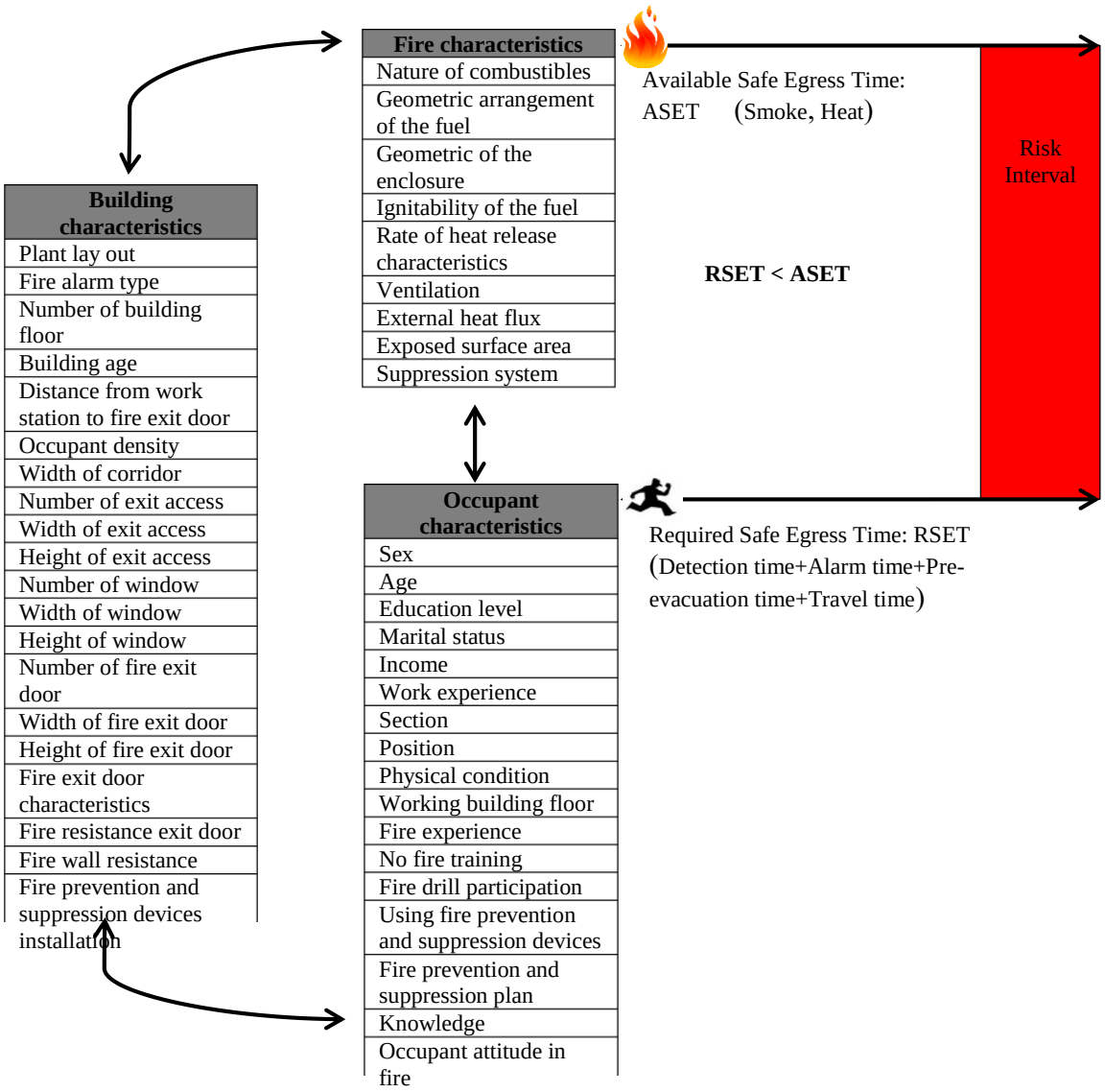

Figure 2. Fire response performance model.

Table 1. Occupant characteristics (N=375).

Occupant characteristics	Frequency	Percent
1. Sex		
Male	114	30.4
Female	261	69.6
2. Age($\bar{x}$ = 33.08, S.D.=8.44)		
5-24 years	62	16.6
25-44 years	269	71.7
45-64 years	44	11.7
65+ years	-	-
3. Education level		
Primary education	48	12.8
Secondary education	247	65.9
Diploma	36	9.6
Bachelor's degree or higher	44	11.7
4. Marital status		
Single	206	54.9
Married	152	40.5
Divorce	16	4.3
Other	1	0.3
5. Income($\bar{x}$ =12,661.98, S.D.=5,986.58)		
≤5,000 Baht	-	-
5,001-10,000 Baht	189	50.4
10,001-15,000 Baht	120	32.0
15,001-20,000 Baht	45	12.0
20,001-25,000 Baht	11	2.9
More than 25,000 Baht	10	2.7
6. Work experience($\bar{x}$ = 83.73, S.D.=84.13)		
0-48 months	194	51.7
49-108 months	59	15.7
109+ months	122	32.6
7. Section		
Production	267	71.2
Engineering/Maintenance	19	5.1
Warehouse	14	3.7
Raw material	2	0.5
Purchasing	5	1.3
Production planning	1	0.3
Safety and environment	1	0.3
Human resources	17	4.5
Finance and accounting	10	2.7
Quality control	20	5.3
Logistic	9	2.4
Other	10	2.7
8. Position		
Subcontractor	2	0.5
Staff	343	91.5

Occupant characteristics	Frequency	Percent
Foreman	25	6.7
Section manager	4	1.1
Other	1	0.2
9. Physical condition		
Not disable	370	98.7
Disable	5	1.3
10. Working building floor		
1st floor	294	78.4
2nd floor	81	21.6
11. Fire experience		
Been through the fire	64	17.1
Never through the fire	311	82.9
12. No fire training participation		
Have attended fire training	315	84.0
Never attended fire training	60	16.0
13. Fire drill participation		
Have attended fire drill	341	90.9
Never attended fire drill	34	9.1
14. Using fire prevention and suppression devices		
Yes	286	76.3
No	89	23.7
15. Fire prevention and suppression plan		
Yes	369	98.4
No	6	1.6
16. Knowledge about fire prevention and suppression ($\bar{x}$ =12.96, S.D.=1.66)		
Good knowledge :14-17 scores (81%-100%)	156	41.6
Neutral knowledge :11-13 scores (60%-80%)	197	52.5
Less knowledge :00-10 scores (less than 60%)	22	5.9
17. Occupant attitude in fire ($\bar{x}$ =67.05, S.D.=11.23)		
Concern attitude :102-125 scores (81%-100%)	-	-
Neutral attitude :75-101 scores (60%-80%)	96	25.6
Not concern attitude :00-74 scores (less than 60%)	279	74.4

3.2 Building characteristics survey

Building characteristics were surveyed by researcher which showed the results in Table 2.

Table 2. Building characteristics (N=375).

Building characteristics	Frequency	Percent
1. Fire alarm type		
Warning system using alarm signal	375	100
2. Number of building floor		
1 floor	204	54.4
2 floor	171	45.6
3. Building age($\bar{x}$ =17.52, S.D.=9.93)		
1-10 years	151	40.3
11-20 years	47	12.5
21-30 years	177	47.2
4. Distance from work station to fire exit door($\bar{x}$ =85.37, S.D.=109.29)		
1-50 m.	251	66.9
51-100 m.	33	8.8
101-150 m.	2	0.5
151-200 m.	18	4.8
201-250 m.	28	7.5
251-300 m.	-	-
301-350 m.	39	10.4
351-400 m.	4	1.1
5. Occupant density ($\bar{x}$ =0.81, S.D.=0.16)		
0.01-0.50 person/m^2	234	62.4
0.51-1.00 person/m^2	66	17.6
1.01-1.50 person/m^2	75	20.0
6. Width of corridor (N= 136,$\bar{x}$ =1.92, S.D.=0.29)		
0.00-1.00 m.	5	3.7
1.01-2.00 m.	121	89.0
2.00-3.00 m.	10	7.3
7. Number of exit access(N= 232,$\bar{x}$ =1.90, S.D.=1.20)		
1 exit access	119	51.3
2 exit accesses	51	22.0
3 exit accesses	43	18.5
4 exit accesses	6	2.6
5 exit accesses	11	4.7
6 exit accesses	-	-
7 exit accesses	2	0.9
8. Width of exit access(N= 232,$\bar{x}$ =1.48, S.D.=0.69)		
0.00-1.00 m.	104	44.8
1.01-2.00 m.	96	41.4
2.01-3.00 m.	25	10.8
3.01-4.00 m.	7	3.0

Building characteristics	Frequency	Percent
9. Height of exit access (N= 232, $\bar{x}$ =2.05, S.D.=0.10)		
Less than 2.00 m.	122	52.6
2.01-4.00 m.	110	47.4
10. Number of window ($\bar{x}$ =4.44, S.D.=11.69)		
None	317	84.5
2 windows	7	1.9
4 windows	1	0.3
6 windows	5	1.3
More than 6 windows	45	12.0
11. Width of window (N= 58, $\bar{x}$ =1.21, S.D.=0.92)		
≤1.5 m.	46	79.3
More than 1.5 m.	12	20.7
12. Height of window (N= 58, $\bar{x}$ =1.66, S.D.=0.25)		
≤2.00 m.	58	100
2.01-4.00 m.	-	-
13. Number of fire exit door(N= 366, $\bar{x}$ =1.98, S.D.=1.29)		
1fire exit door	164	44.8
2 fire exit doors	128	35.0
3 fire exit doors	19	5.2
4 fire exit doors	45	12.3
More than 4 fire exit doors	10	2.7
14. Width of fire exit door(N= 366, $\bar{x}$ =2.23, S.D.=2.01)		
Less than 1.00 m.	190	51.9
1.01-2.00 m.	77	21.0
2.01-3.00 m.	15	4.1
3.01-4.00 m.	12	3.3
4.01-5.00 m.	30	8.2
More than 5.00 m.	42	11.5
15. Height of fire exit door (N= 366, $\bar{x}$ =2.49, S.D.=0.83)		
Less than 2.00 m.	55	15.0
2.01-4.00 m.	279	76.2
More than 4.00 m.	32	8.8
16. Fire exit door characteristics		
Slide exit door	20	5.3
Roll-shutter exit door	72	19.2
Pushed out of the exit door	283	75.5
17. Fire resistance exit door		
Yes	171	45.6
No	204	54.4
18. Fire wall resistance		
Yes	329	87.7
No	46	12.3
19. Fire prevention and suppression devices installation		
19.1 Fire extinguisher		
Yes	375	100
No	-	-

Building characteristics	Frequency	Percent
19.2 Sprinkler system		
Yes	129	34.4
No	246	65.6
19.3 Manual detection		
Yes	365	97.3
No	10	2.7
19.4 Smoke detector		
Yes	129	34.4
No	246	65.6
19.5 Heat detector		
Yes	106	28.3
No	269	71.7
19.6 Flame detector		
Yes	105	28.0
No	270	72.0

3.3 Relationship between occupant characteristics, building characteristics and pre-evacuation time

The findings revealed that number of building floors, building age, number of windows, number of fire exit doors, distance from work station to fire exit door, width of fire exit door, and occupant characteristics: no fire training participation, occupant attitude in fire related to pre-evacuation time is shown in Table 3. Regression analysis covers eight affected variables from those analysis. Only four influenced variables were tested by using regression analysis as shown in Table 4. The regression analysis model formula is shown in Equation (1).

The formula obtained using stepwise multiple regression analysis model is:

$$Y = 693.846 - 6.620X_1 - 84.290X_2 + 112.992X_3 + 5.143X_4 \quad (1)$$

Where

Y = Pre-evacuation time (second)

X_1 = Occupant attitude in fire

X_2 = Number of fire exit door

X_3 = No fire training participation

X_4= Distance from work station to fire exit door (meter)

4. Discussion

There are eight items related to pre-evacuation time in fire of medium plastic industries in Thailand (P<0.05) . These are number of building floors, building age, number of window, number of fire exit door, distance from work station to fire exit door, width of fire exit door, no fire training participation and occupant attitude in fire. Number of building floors, there is a positive relationship with pre-evacuation time because of the most of people had been working on the first floor (78.4%) when a fire occurred after fire alarm bell rings can move toward safe place easily that will be made decreasing pre-evacuation time which according with Kobes, M. [13] has been found on the correlation between the possibility of a safe escape and the height of a building. Experience of fatal fires in buildings with more stories has shown that there is a high probability of fire or smoke in their staircases. Building age, there is a negative relationship with pre- evacuation time which there is a possibility that the most people believe in fire prevention and suppression devices installation in a new building. No information was found in the literature about the influence of building age on pre-evacuation time. Number of windows and number of fire exits, there is a negative

relationship with pre-evacuation time as with building age. Distance from work station to fire exit door, there is a positive relationship with pre-evacuation time. No information was found in the literature about the influence of distance from work station to fire exit door on pre-evacuation time. However, data has been found on a negative correlation between width of fire exit door and pre-evacuation time. No fire training participation, there is a positive relationship with pre-evacuation time that will be made increasing pre-evacuation time if they have attended in the fire training which according with LI Li-min and ZHU Guo-qing [14] has been found on the correlation between fire training with response time, The majority of them received fire drill or training has had the personal's response time within 1 minute. Finally, occupant attitude in fire had a negative correlation with pre-evacuation time as the result of the most people had not been concerned attitude in fire (77.4%) that will be made increasing pre-evacuation time. A multiple regression model was run to predict pre-evacuation time from four influenced variables.

These variables statistically significantly predicted pre-evacuation time, F= 15.256, $p < 0.05$, $R^2 = 0.871$, the regression model is a good fit of the data.

5. Conclusion

An evaluation of the Required Safe Egress Time (RSET) is a crucial step in the fire response performance. RSET consisted of four components; which are detection time, alarm time, pre-evacuation time and travel time or movement time. Pre-evacuation time is also essential of RSET. Consequently, pre-evacuation time is currently regarded as the key aspects of evacuation process. There are three critical factors determine the degree of fire response performance in the event of fire in a building for surviving. These are fire characteristics which is not considered in this research as the result of uncontrollable factor, occupant characteristics and building characteristics. Therefore, in the paper focused on the features of each factors and study relationship between occupant, building characteristics and pre-evacuation time including influenced variables consisted of occupant attitude in fire, number of fire exit door, no fire training participation, and distance from work station to fire exit door to predict pre-evacuation time.

Table 3. Relationship between independent variables and pre-evacuation time (N=375).

Independent Variables	Pearson's correlation	*P*-Value*
Number of building floor	0.238	0.000
Building age	-0.288	0.000
Number of window	-0.310	0.000
Number of fire exit door	-0.277	0.000
Distance from work station to fire exit door	0.160	0.002
Width of fire exit door	-0.165	0.002
No fire training participation	0.133	0.010
Occupant attitude in fire	-0.155	0.003

*p-value < 0.05

Table 4. Regression analysis model (N=375).

Independent Variables	Unstandardized Coefficients		t	*P*-Value*
	B	Std.Error		
Constant	693.846	150.913	4.598	0.001
Occupant attitude in fire	-6.620	2.036	-3.252	0.010
Number of fire exit door	-84.290	20.383	-4.135	0.003
No fire training participation	112.992	49.060	2.303	0.047
Distance from work station to fire exit door	5.143	2.265	2.270	0.049
$R=0.934$ $R^2 = 0.871$ Std.Error = 59.866 F=15.256 *P*-Value = 0.00				

*p-value < 0.05

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