工學碩士 學位論文

선박조종시뮬레이션의 최저 시행에 관한 연구

A Study on Minimum Runs of Ship-handing Simulation

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Abstract

In the year of 2010 the Korean government introduced an enforced maritime traffic safety assessment act for the purpose of enhancing traffic safety. The act was mandated by the law to design a new port or modify an exiting one. According to Korea Maritime Safety Act, the assessment of propriety of marine traffic system comprises safety of channel transit and berthing/unberthing maneuver, safety of mooring, and safety of marine traffic flow. The safety of channel transit and berthing/unberthing maneuver can be evaluated only by ship-handling simulation which is carried out by sea pilots working with the port concerned. The vessel's proximity measure is an important factor for evaluating traffic safety. The proximity measure is composed of vessel's closest distance to channel boundary and probability of grounding/collision. Therefore, the probability of grounding cannot be ignored.

According to central limit theorem, a sample has a normal distribution on condition that its size is more than 30. However, more than 30 simulation runs lead to an increase in the assessment period which results in difficulty in employing sea pilots. Hence, this paper aims to analyze the minimum sample size for evaluating vessel's proximity.

In this research, mean and standard deviation of ten cases are obtained from the latest maritime traffic safety assessment. The probability of grounding is within 10^{-4}. Then each case generates twenty random sample sets, each set constitutes the sample 3, 4, 5, 6, 7, 9 and 11, at the same time it calculates the h value and confidence interval of each sample sets. Then the box-plots which consists of twenty sample boxes is drawn, and the mean line and confidence interval are

also shown on the box-plots. In the box-plots, the X-axis refers to the sample set, while the Y-axis is CPA to channel boundary. Based on the size of confidence interval, the change of confidence interval span, the relative position of mean line and box figures, it can be indicated that the minimum number of simulation should be more than 5.

After accumulating the mean and standard deviation curves of confidence interval, when the size of simulation runs is larger than 5, a much smaller mean and standard deviation of confidence interval than those in 3 can be obtained.

In each case of this study, the 20 sample sets of data are obtained randomly by the parameter mean and standard deviation. If the actual data is used, it is difficult to ensure the 20 sample sets of actual data have the same mean and standard deviation. As such, it is meaningless to use the actual data to analyse. Thus this study uses the random data instead of actual data to analyse.

In conclusion, this paper proposes a minimum sample size of 5, that is, the simulation should be carried out more than five times. It is recommended that actual data should be used to carry out analysis and other tests other than KS test should be applied to goodness of fit for the sample distribution.

Key words: minimum sample size; vessel's proximity measure; maritime traffic safety assessment; Korea Maritime Safety Act; propriety of marine traffic system; ship-handling simulation

1. Introduction

1.1 Background and purpose of the study

In 2010, the Korean government enforced the maritime traffic safety assessment in order to improve the safety of sea transportation in the harbor and harbor approaches (MOF. 2013a). The maritime traffic safety assessment has a legal obligation to design a new port or modify an existing one. According to the Korea Maritime Safety Act, the assessment is composed of five items: investigation of marine traffic environment; measurement of marine traffic; propriety of marine traffic system; safety measure of marine traffic and comprehensive evaluation (MOF, 2013b). The propriety of marine traffic system consists of three sub-items, that is, the safety of channel transit and berthing/unberthing maneuver, safety of mooring, and safety of marine traffic flow. The safety of channel transit and berthing/unberthing maneuver can be evaluated only by ship-handling simulation which is carried out by sea pilots working with the port concerned. In the result of the ship-handling simulation the vessel's proximity measure is an important factor to evaluate traffic safety. The proximity measure is composed of vessel's closest distance to channel boundary and probability of grounding/collision. According to the Korean Maritime Traffic Safety Assessment, the probability of grounding should be less than 0.0001 or 10^{-4}. In addition, since the simulation run should be more than three times, the assessment may be carried out three times.

According to central limit theorem, a sample has a normal distribution on condition that its size is more than 30 (Kim et al, 1999). In practice, more than 30 simulation runs bring about the increase of assessment period and difficulty of employing sea pilots. Jeong (2014) presented the outline of the minimum sample in ship-handling simulation, which was not fully based on statistics. Therefore this paper aims to analyze minimum sample size for evaluating vessel's proximity on the basis of statistics. At first sample sets of size of 3, 5,

7, 9 etc. are selected randomly on the basis of normal distribution. Subsequently, the KS test for goodness of fit and confidence interval of the t-test are applied to each sample set.

In each case of this study, the 20 sample sets of data is obtained randomly by the parameter mean and standard deviation. If the actual data were used, it would be difficult to ensure the 20 sample sets of actual data have the same mean and standard deviation. Therefore it is meaningless to use the actual data to analyse. Thus this study uses the random data instead of actual data for analysis.

1.2 Related researches of the study

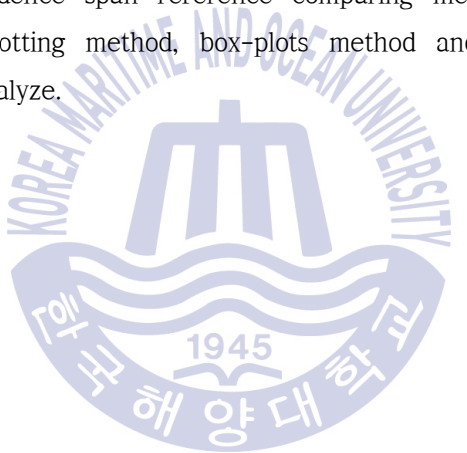
Prof. Jong published the thesis titled ‘A Study on Minimum Number for Evaluating Vessel’s Proximity Measure in Ship-handing Simulation’ in Korea Institute of Navigation and Port Research in 2014. His research proposed that setting the minimum sample sets as 3 was the question by using KS-test and CDF comparison method. At the end of 2014, his thesis ‘A Study on Minimum Number of Ship-handling Simulation Required for Evaluating Vessel’s Proximity Measure’ using the confidence interval t-test and box-plots comparison method concluded that the minimum number of tests should be five. However, the objectives of the two researches were both based on one set of experimental data generated from Matlab. The former sample set is one, the latter is twenty. From the viewpoint of probability to illustrate, this paper utilizes ten cases of data, and each case has 20 sample sets.

1.3 Methodology of the study

In statistics, a confidence interval (CI) is a type of interval estimate of a population parameter. It is an observed interval, in principle different from sample to sample, that frequently includes the value of an unobservable

parameter of interest if the experiment is repeated. How frequently the observed interval contains the parameter, which is determined by the confidence level. More specifically, the meaning of the term "confidence level" is that, if CI is constructed across many separated data analyses of replicated experiments, the proportion of such intervals that contains the true value of the parameter will match the given confidence level. Whereas two-sided confidence limits form a confidence interval, their one-sided counterparts are referred to as lower or upper confidence bounds.

This study uses the parameters to generate the random samples, then calculates the confidence interval span by t-test. In the analysis stages, this study uses the confidence span reference comparing method, the mean and standard deviation plotting method, box-plots method and superposed curves plotting method to analyze.



2. Design of the study

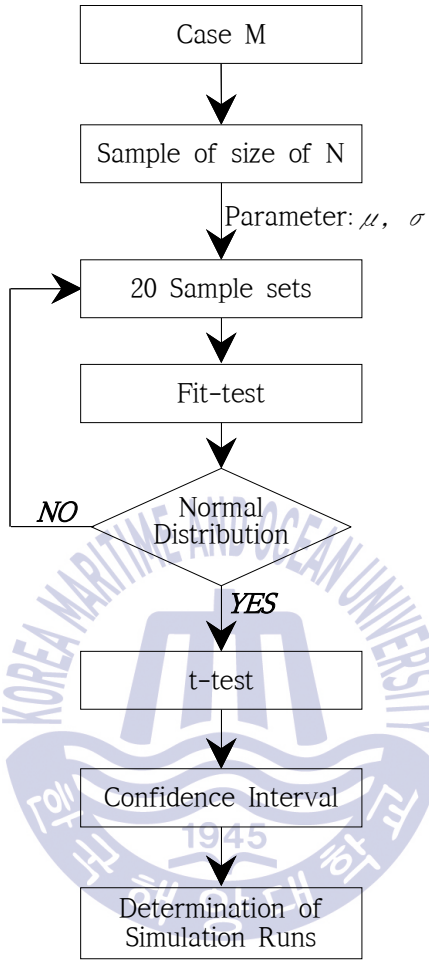
2.1 Population and sample

A population includes all of the elements from a set of data and a sample consists of one or more observations from the population. Generally, when researchers do some study on population, it is impossible to do because the amount of the population is large enough. So, the sample is usually used to estimate the attributes of the population.

In this study, when the simulation runs equals to 3, the population is all of CPA of 3 times experiments. Sample is the 20 groups of data extracted from the populations. The Table 3.2 shows the sample sets when simulation runs equals to 3. After testing these sample sets, the confidence interval can be calculated, which is also shown in Table 3.2.

2.2 Research process

In the research, mean and standard deviation of ten cases are obtained from the latest maritime traffic safety assessment. The probability of grounding is within 0.0001. Then each case generates twenty random sample sets, each set constitutes the sample 3, 4, 5, 6, 7, 9 and 11, at the same time to calculate the h value and confidence interval of each sample sets. Then the box-plots which consists of twenty sample boxes is plotted, and the mean line and confidence interval are also shown on the box-plots. In the box-plots, the X-axis stands for the sample set, while the Y-axis is CPA to channel boundary. Based on the size of confidence interval, the change of confidence interval span, the relative position of mean line and box figures, it is clear that the minimum number of simulation should be more than 5.



where: M=[1 2 3 4 5 6 7 8 9 10];
N=[3 4 5 6 7 9 11];
μ: Mean; σ:Standard Deviation;

Fig. 2.1 The Process of the study

As shown in Fig. 2.1, the process of the study can be separated to 8 steps in general:

1). Determinate the parameters of ten cases;

2). Each case consists of samples of size of 3, 4, 5, 6, 7, 9, 11;

3). Using the parameters mean and standard deviation of CPA generate 20 sample sets randomly.

4). Test each set by KS test, obtain the h value.

5). Determinate if the set is normal distribution by the h value of this set.

6). Test each set by t-test.

7). Obtain the confidence interval and confidence interval span of each set.

8). Determinate the minimum simulation runs.

In summary, the study uses random method to generate the data, then uses the statistics methods(KS-test, t-test) to test the sample set. After analyzing by box-plots, compare method, mean and standard deviation of confidence interval span plot method and superposed confidence interval span plot method, the study suggests the minimum simulation runs.

2.3 Statistical method in the study

In this study, box-plots measure and normal distribution function measure are combined to analyse the relative position of box-plots and normal distribution function when the sample size is 3, 4, 5, 6, 7, 9 and 11. It is easy to find the fluctuation of each sample sets.

2.3.1 Introduction of box-plots

In matlab boxplot(X) produces a box plot of the data in X. If X is a matrix, there is one box per column; if X is a vector, there is just one box. On each box, the central mark is the median, the edges of the box are the 25^{th} and 75^{th} percentiles, the whiskers extend to the most extreme data points not considering outliers, and outliers are plotted individually.

The confidence interval of each sample set is given by the symbols of '×'. The tops and bottoms of boxes are the 25^{th} and 75^{th} percentiles of

sample sets. In the box plots, the median is denoted by the symbol '—' and the whiskers are denoted by '⊥' or '┬' which extend to the most extreme data points.

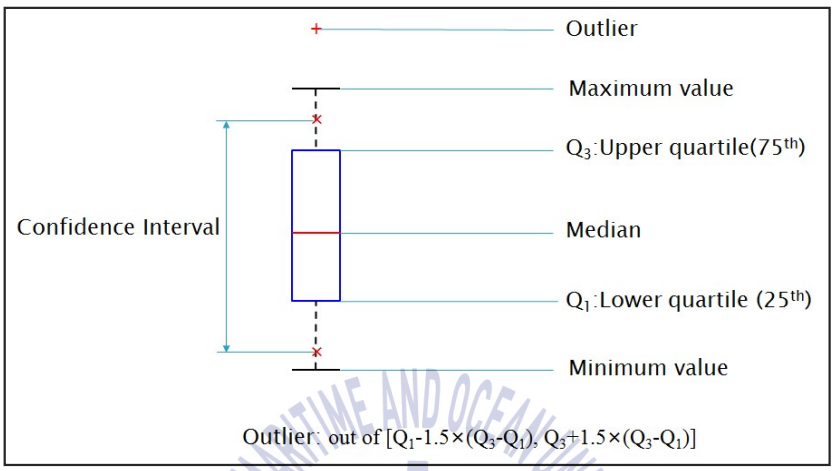


Fig. 2.2 The meaning of box-plot

2.3.2 The use of box-plots and normal distribution function

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

f(x) is Probability Density Function, μ is mean, σ is standard deviation, the probability of x between x_1 and x_2 is as followed :

$$P(x_1 < X < x_2) = \Phi\left(\frac{x_2 - \mu}{\sigma}\right) - \Phi\left(\frac{x_1 - \mu}{\sigma}\right)$$

where, $\Phi(x)$ means the standard normal distribution function.

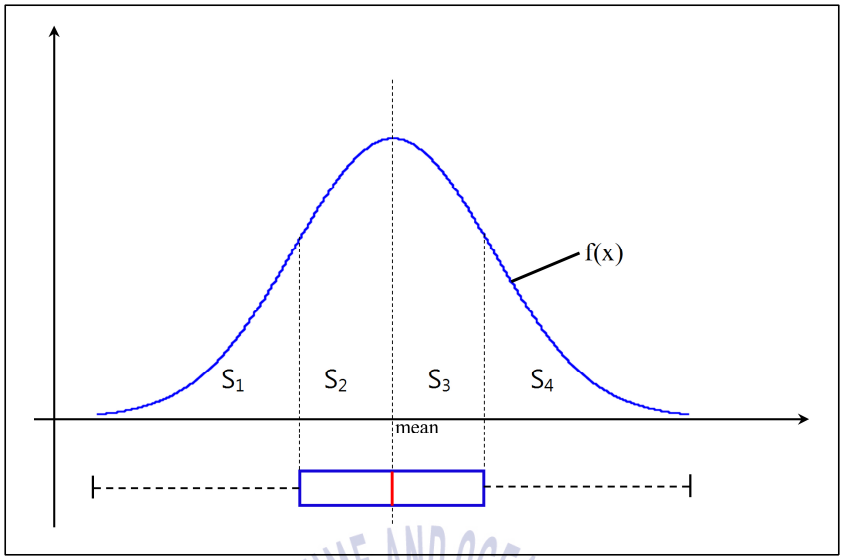


Fig. 2.3 The relationship between the box-plot and normal distribution

As shown in Fig. 2.3, if the distribution function is normal distribution function, the square of the Probability Density Function should be $S_2+S_3=0.5$ when x is in the interval from 25th to 75th of the box-plot.

$$P(x_1 < X < x_2) = 0.5$$

$x_1 = \mu - 0.6745\,\sigma$; $x_2 = \mu + 0.6745\,\sigma$.

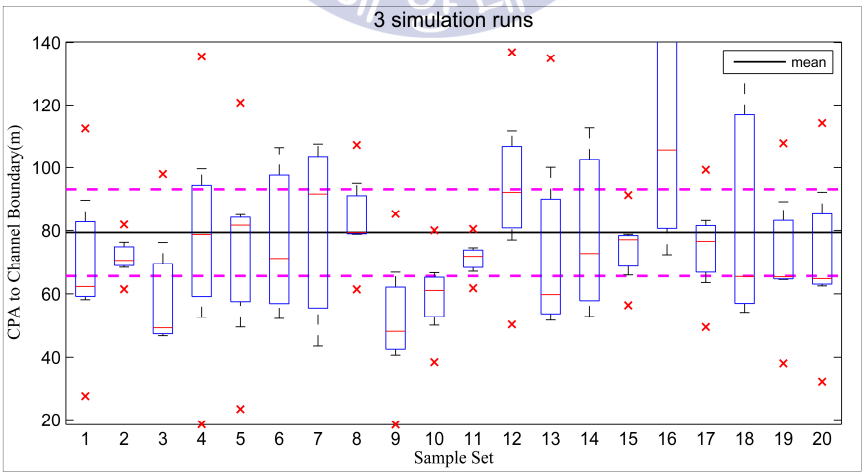


Fig. 2.4 The box-plots of 3 simulation runs(μ =79.35, σ =20.29)

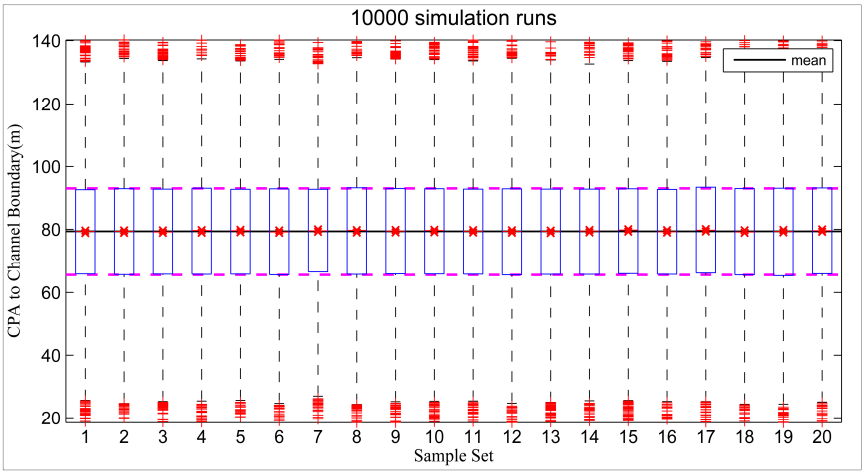


Fig. 2.5 The box-plots of 10000 simulation runs(μ =79.35, σ =20.29)

Fig. 2.4 and Fig. 2.5 are the box-plots of 20 sample sets of 3 and 10000 simulation runs. With the value of μ and σ, the interval of x can be calculated when P is 0.5. It is [65.55, 93.15] which is the dotted line shown in the figure. With the increase in simulation runs, the interval from 25th to 75th of the box-plots will tend to [65.55, 93.15].

3. Generation and analysis of random sample sets with less than collision probability of 10^{-5}

3.1 Determination of parameters for generation of random sample set

It is important to note that the generation of the random sample sets is based on the condition that the population is normally distributed. In addition, the collision or grounding probability is less than 10^{-5}. The following table indicates 5 cases which are obtained from the latest maritime traffic safety assessment.

Table 3.1 The mean and standard deviation of each case

Case	Mean	Standard Deviation	Collision Probability
1	79.35	20.29	4.59×10^{-5}
2	98.57	23.87	1.82×10^{-5}
3	99.50	24.33	2.16×10^{-5}
4	99.34	21.48	1.88×10^{-6}
5	83.72	18.62	3.46×10^{-6}

Using the above parameters, this paper generates 5 cases of sample sets randomly. Each case of sample set is with the size of 3, 4, 5, 6, 7, 9, and 11. Each random sample set will be composed of 20 simulation sets. Each sample set is tested by KS test and t-test. And the confidence interval of each sample set is given (Math Works, 2014).

3.2 Generation and analysis of random sample set from case 1 to case 5

3.2.1 Data of case 1

Case 1:

Average : μ=79.35(m)

Standard deviation : σ^2=20.29^2

Collision probability : 4.60×10^{-5}

Table 3.2 Sample sets of three(3) runs

	1	2	3	4	5	6	7	8	9	10
1	98.59	103.12	97.2	75.18	92.17	55.2	35.92	109.95	50.07	93.82
2	93	123.3	86.68	52.34	114.61	84.83	78.87	85.34	64.29	72.72
3	84.66	104.84	48.1	66.79	28.11	128.29	77.16	66.61	106.02	46.56
h	0	0	0	0	0	0	0	0	0	0
p	0.93	0.71	0.81	0.91	0.84	0.93	0.67	0.95	0.84	0.96
CI	74.68	82.64	13.1	36.07	-33.21	-1.89	3.57	33.3	1.22	12.22
	109.49	138.21	141.55	93.46	189.8	180.77	124.39	141.3	145.7	129.85
	(34.81)	(55.58)	(128.45)	(57.39)	(223.01)	(182.65)	(120.82)	(108.01)	(144.48)	(117.64)
	11	12	13	14	15	16	17	18	19	20
1	106.56	92.28	121.16	79.52	71.67	80.21	74.82	109.06	92	54.8
2	69.44	99.04	80.87	48.08	90.39	105.87	78.8	77.49	104.18	81.58
3	91.4	78.43	97.22	63.94	60.45	70.34	109.65	53.02	58.41	79.75
h	0	0	0	0	0	0	0	0	0	0
p	0.94	0.88	0.93	0.99	0.91	0.85	0.74	0.96	0.84	0.7
CI	42.77	63.82	49.42	24.79	36.59	39.91	40.39	10.07	25.97	34.88
	135.5	116.01	150.08	102.9	111.75	131.03	135.12	149.64	143.76	109.2
	(92.73)	(52.19)	(100.66)	(78.11)	(75.16)	(91.12)	(94.72)	(139.57)	(117.79)	(74.33)

Table 3.3 Sample sets of four(4) runs

	1	2	3	4	5	6	7	8	9	10
1	83.65	71.48	79.74	76.19	73.82	99.22	67.04	41.76	80.2	66.06
2	61.58	109.65	70.25	87.13	69.55	109.17	69.21	83.04	99.36	109.56
3	89.78	132.03	65.29	65.7	91.65	70.66	64.01	120.85	100.49	84.44

4	77.16	83.53	44.81	79.08	25.87	98.85	66.04	76.59	67.19	68.1
h	0	0	0	0	0	0	0	0	0	0
p	0.93	0.93	0.89	0.93	0.73	0.59	0.97	0.93	0.82	0.89
CI	58.75	56.08	41.56	62.93	20.78	68.09	63.13	28.99	61.26	50.04
	97.33	142.27	88.49	91.12	109.66	120.86	70.01	132.13	112.36	114.03
	(38.59)	(86.19)	(46.93)	(28.19)	(88.88)	(52.77)	(6.88)	(103.13)	(51.10)	(63.99)
	11	12	13	14	15	16	17	18	19	20
1	114.23	64.48	74.35	99.23	90.11	74.6	91.39	76.14	91.71	114.89
2	99.59	81.75	92.83	57.06	72.98	76.68	70.32	68.82	44.8	70.33
3	91.7	84.89	92.09	68.64	91.71	92.68	122.69	99.51	85.85	84.11
4	87.87	82.91	73.13	74.59	87.05	71.29	67.4	56.22	65.84	76.4
h	0	0	0	0	0	0	0	0	0	0
p	0.93	0.49	0.78	0.89	0.69	0.64	0.89	0.92	0.91	0.78
CI	79.8	63.49	65.88	46.56	71.86	63.69	47.37	46.23	38.2	54.93
	116.9	93.53	100.32	103.19	99.06	93.94	128.54	104.11	105.91	117.93
	(37.10)	(30.04)	(34.44)	(56.63)	(27.20)	(30.25)	(81.17)	(57.89)	(67.72)	(62.99)

Table 3.4 Sample sets of five(5) runs

	1	2	3	4	5	6	7	8	9	10
1	66.47	88.61	85.69	95.23	47.48	89.49	51.9	89.96	90.71	65.93
2	61.06	82.37	80.21	42.06	79.61	72.14	68.66	77.09	76.32	71.04
3	65.11	86.72	79.38	99.08	93.51	84.19	78.03	141.07	88.25	86.77
4	101.32	71.53	57.14	87.66	40.69	62.83	94.49	61.39	106.52	98.39
5	73.23	78.78	97.59	92.21	55.9	95.42	82.99	66.63	107.35	88.95
h	0	0	0	0	0	0	0	0	0	0
p-value	0.64	0.97	0.73	0.38	0.9	0.96	0.97	0.79	0.89	0.89
CI	53.33	73.15	61.75	54.19	35.71	64.41	55.32	47.47	77.51	65.58
	93.54	90.06	98.26	112.3	91.17	97.22	95.11	126.99	110.15	98.85
	(40.21)	(16.90)	(36.51)	(58.11)	(55.46)	(32.81)	(39.78)	(79.51)	(32.65)	(33.27)
	11	12	13	14	15	16	17	18	19	20
1	103.53	106.71	82.32	107.75	74.33	82.2	80.3	87.89	54.77	101.49
2	116.81	90.66	76.63	58.62	101.71	41.97	79.78	91.32	88.04	57.08
3	64.16	85.57	93.62	70.39	80.9	90.24	67	73.67	56.37	69.16
4	99.55	69.15	114.64	63.16	74.31	55.84	89.24	76.79	83.65	99.12
5	80.95	97.92	63.58	83.39	70.77	55.96	98.23	81.21	83.09	97.57
h	0	0	0	0	0	0	0	0	0	0
p-value	0.91	0.97	0.97	0.91	0.71	0.75	0.96	0.97	0.55	0.53

CI	67.42	72.48	62.25	52.15	64.93	40.19	68.42	73	53.07	59.59
	118.58	107.52	110.06	101.18	95.88	90.3	97.39	91.35	93.3	110.18
	(51.15)	(35.04)	(47.81)	(49.03)	(30.94)	(50.10)	(28.97)	(18.35)	(40.23)	(50.59)

Table 3.5 Sample sets of six(6) runs

	1	2	3	4	5	6	7	8	9	10
1	51.99	56.43	89.66	113.56	81.39	89.94	70.05	88.42	87.71	90.8
2	91.17	73.62	52.65	54.1	108.23	59.7	81.66	75.4	96.01	88.19
3	101.05	86.57	72	45.68	143.19	113.61	46.65	65.71	69.75	96.2
4	97.96	48.97	53.61	85.82	80.75	99.84	97.13	101.13	69.68	100.14
5	93.56	88.35	64.85	73.92	70.21	73.66	77.71	57.37	79.35	90.12
6	73.66	74.63	42.23	114.59	108.72	95.12	104.41	65.19	81.2	66.74
h	0	0	0	0	0	0	0	0	0	0
p-value	0.56	0.87	0.93	0.93	0.8	0.95	0.99	0.86	0.96	0.49
CI	65.24	54.77	44.81	50.75	70.57	68.43	58.06	58.26	69.84	76.5
	104.56	88.09	80.19	111.81	126.92	108.86	101.15	92.81	91.39	100.9
	(39.32)	(33.32)	(35.38)	(61.06)	(56.35)	(40.43)	(43.09)	(34.54)	(21.55)	(24.40)
	11	12	13	14	15	16	17	18	19	20
1	101.88	102.78	99.6	87.71	89.79	47.39	78.24	127.11	79.8	65.1
2	100.22	80.08	55.71	93.29	99.71	87.47	110.77	100.89	78.72	36.79
3	101.22	95.86	111.56	72.11	112.7	100.17	96.29	67.44	102.11	94.54
4	70.53	72.45	88.16	78.04	96.29	93.31	85.04	111.38	113.62	94.91
5	64.37	93.53	73.12	97.52	86.74	89.37	84.12	54.3	106.59	55.43
6	74.29	80.33	48.8	76.93	62.69	78.17	79.65	81.81	75.29	73.48
h	0	0	0	0	0	0	0	0	0	0
p-value	0.55	0.84	0.98	0.84	0.86	0.69	0.59	0.99	0.64	0.95
CI	67.07	75.33	53.55	73.68	73.79	63	76	61.55	75.23	46.23
	103.77	99.68	105.43	94.86	108.85	102.29	102.04	119.43	110.15	93.85
	(36.70)	(24.35)	(51.89)	(21.18)	(35.06)	(39.29)	(26.04)	(57.88)	(34.92)	(47.62)

In these tables, the parentheses in the confidence interval column describe the range of the interval. In Table 3.2 of three simulation runs, 16 sets of 20 have the range of confidence interval of more than 70. They are underlined and shaded. In Table 3.3 of four runs, 4 sets of 20 have the range of confidence interval of more than 70. In Table 3.4 of five runs, 1 set of 20 has the range of confidence interval of more than 70. However, in Table 3.5 of six

runs, no set of 20 is over the range of confidence interval of 70.

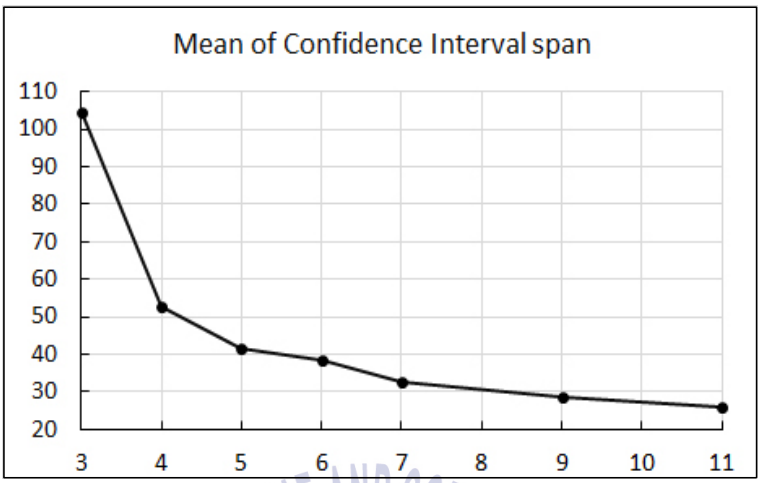


Fig. 3.1 Mean of confidence interval span of case1

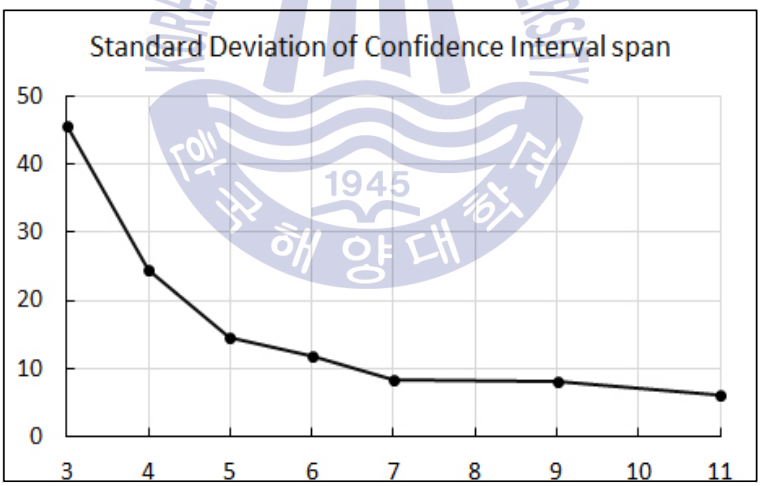


Fig. 3.2 Standard deviation of confidence interval span of case1

As shown in Fig. 3.1, when the simulation runs are 3 and 4, the slope of the curve is very big. But after 5 the curve becomes relatively smooth. The same situation is shown in Fig. 3.2, When the simulation runs is more than 5, the curve becomes smooth. This indicates that after 5 simulation runs the result is beginning to stabilize.

3.2.2 Box-figures and confidence interval of case 1

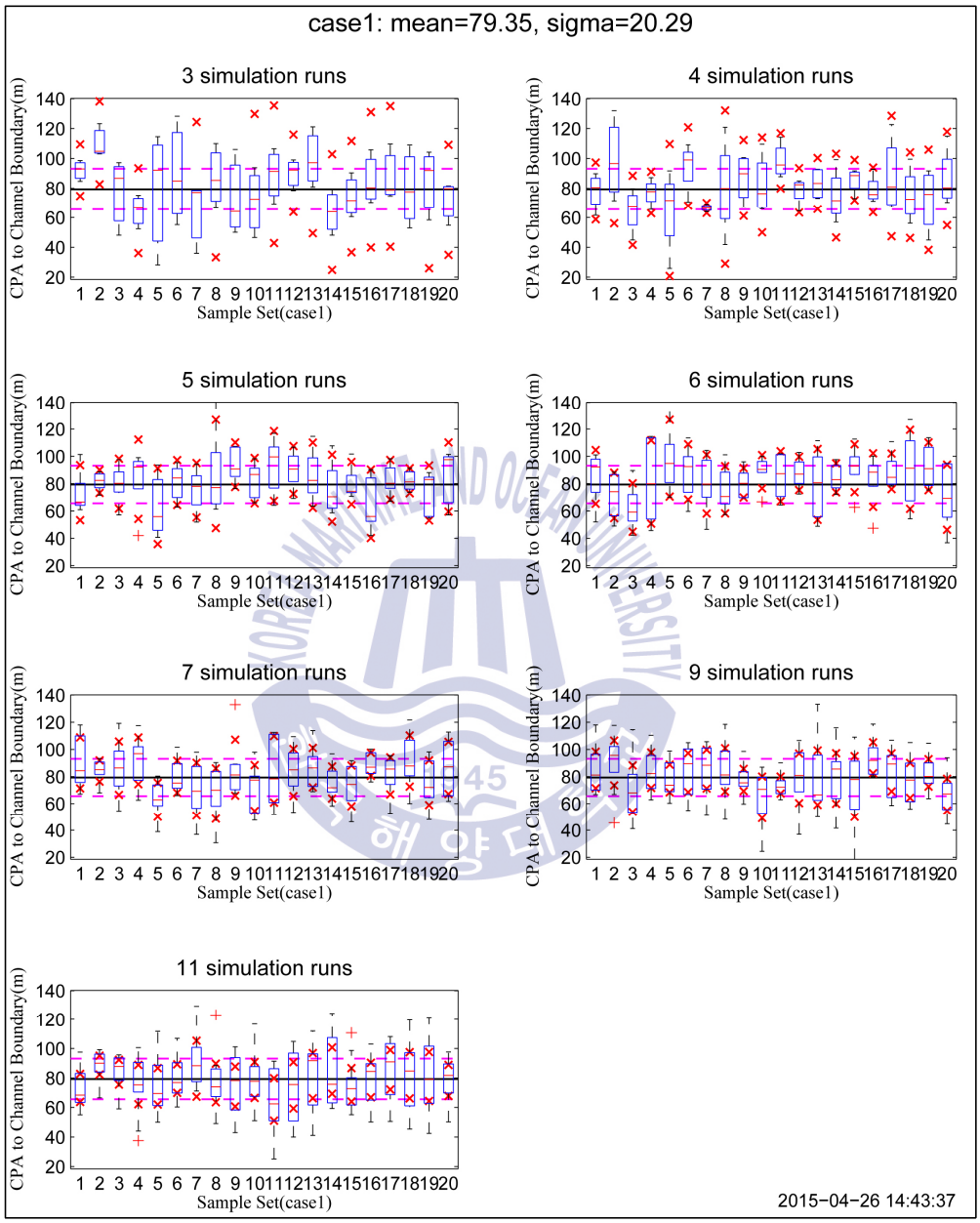


Fig. 3.3 Box-plots of case 1

As shown in Fig. 3.3, when the size of simulation runs is 3 or 4, the box interval of each box-plot fluctuates wildly, some boxes deviate from the

interval [65.55, 93.15] seriously, such as set 2 and set 13 in 3 simulation runs. At the same time the range of some boxes is significant, such as set 2 and set 4 in 4 simulation runs. When the simulation runs more than 5, the box of each box-plot approximates to interval [65.55, 93.15] gradually.

3.2.3 Data of case 2

Case 2:

Average : μ=98.57(m)

Standard deviation : σ^2=23.87^2

Collision probability : 1.82×10^{-5}

Table 3.6 Sample sets of three(3) runs

	1	2	3	4	5	6	7	8	9	10
1	76.51	115.63	86.27	131.99	109.81	118.99	115.88	99.09	116.97	95.78
2	156.24	113.69	132.57	128.66	137.05	115.2	116.44	88.89	68.57	100.64
3	45.69	118.05	105.18	92.04	131.49	119.6	141.08	110.12	57.83	136.24
h	0	0	0	0	0	0	0	0	0	0
p	0.85	0.96	0.94	0.71	0.81	0.77	0.66	0.99	0.79	0.75
CI	-48.9	110.37	50.18	62.5	90.37	112	88.72	73	2.87	56.02
	234.53	121.21	165.84	172.63	161.87	123.86	160.21	125.74	159.38	165.76
	(283.43)	(10.84)	(115.66)	(110.12)	(71.50)	(11.86)	(71.49)	(52.74)	(156.51)	(109.75)
	11	12	13	14	15	16	17	18	19	20
1	126.75	169.08	117.13	83.63	89.75	112.67	109.35	107.72	141.28	83.22
2	132.14	89.09	115.7	91.53	104.33	117.15	125.69	79.22	86.38	58.87
3	96.43	108.56	99.33	142.93	120.02	82.39	99.96	96.3	134.51	123.78
h	0	0	0	0	0	0	0	0	0	0
p	0.78	0.83	0.71	0.76	0.99	0.75	0.91	0.93	0.75	0.91
CI	70.62	18.62	86.15	26.05	67.1	57.1	79.33	58.79	46.37	7.17
	166.26	225.86	135.29	186.01	142.31	151.04	144.01	130.04	195.08	170.08
	(95.63)	(207.24)	(49.14)	(159.96)	(75.21)	(93.94)	(64.68)	(71.25)	(148.71)	(162.92)

Table 3.7 Sample sets of four(4) runs

	1	2	3	4	5	6	7	8	9	10
1	86.64	132.04	75.44	138.93	84.85	124.82	59.1	94.55	99.19	57.95
2	149.42	124.76	135.38	113.03	66.51	104.79	106.32	90.69	130.15	54.02

3	89.55	95.9	64.16	95.06	66.15	92.44	80.09	129.39	77.62	115.16
4	82.25	143.71	96.83	66	105.74	91.89	79.17	110.26	114.84	83.17
h	0	0	0	0	0	0	0	0	0	0
p	0.43	0.88	0.93	0.99	0.84	0.87	0.85	0.91	0.97	0.89
CI	51.4	91.7	43.05	54.44	50.94	78.95	50.36	78.2	69.73	32.72
	152.53	156.5	142.85	152.07	110.68	128.02	111.98	134.25	141.17	122.43
	(101.13)	(64.79)	(99.80)	(97.63)	(59.74)	(49.07)	(61.62)	(56.05)	(71.44)	(89.71)
	11	12	13	14	15	16	17	18	19	20
1	123.53	83.48	66.26	113.2	91.4	86.94	108.15	78.68	129.8	72.97
2	98.55	174.21	95.13	97.46	116.79	97.23	82.38	89.6	88.41	75.42
3	133.44	94.39	65.3	74.46	87.05	111.68	104.56	159.63	80.87	138.15
4	73.63	86.8	136.26	73.4	101.19	99.71	72.79	153.15	115.48	88.65
h	0	0	0	0	0	0	0	0	0	0
p	0.92	0.47	0.86	0.82	0.93	0.93	0.86	0.82	0.91	0.72
CI	64.62	40.92	37.66	59.02	78.12	82.72	64.72	53.38	67.18	45.48
	149.96	178.52	143.81	120.24	120.09	115.06	119.22	187.16	140.1	142.11
	(85.34)	(137.60)	(106.15)	(61.22)	(41.97)	(32.34)	(54.51)	(133.78)	(72.92)	(96.63)

Table 3.8 Sample sets of five(5) runs

	1	2	3	4	5	6	7	8	9	10
1	95.24	74.79	114.89	100.97	67.68	60	74.67	106.64	97.35	93.59
2	107.92	96.25	92.57	78.1	135.55	59.11	98.11	123.06	125.13	81.67
3	61.35	130.36	110.65	116.55	77.24	48.64	70.54	127.53	98.75	97.76
4	93.08	114.59	100.5	40.72	101.17	92.87	100.28	137.67	133.21	106.33
5	69.56	54.52	108.27	113.39	86.99	153.45	134.36	58.48	119.11	92.82
h	0	0	0	0	0	0	0	0	0	0
p-value	0.83	0.98	0.91	0.88	0.96	0.65	0.91	0.83	0.87	0.91
CI	61.45	56.45	94.37	50.96	60.87	29.62	63.95	71.87	94.82	83.35
	109.41	131.76	116.38	128.93	126.58	136	127.23	149.48	134.6	105.52
	(47.97)	(75.31)	(22.01)	(77.97)	(65.71)	(106.38)	(63.28)	(77.61)	(39.77)	(22.17)
	11	12	13	14	15	16	17	18	19	20
1	133.42	81.5	111.53	84.43	67.87	101.57	78.69	100.33	54.47	120.3
2	111.04	105.18	93.62	94.14	113.02	95.7	125.26	132.81	97.77	75.49
3	107.63	81.69	123.89	99.63	118.64	91.42	78.46	119.92	104.1	142.67
4	100.39	121.73	140.42	104.37	117.76	126.7	67.08	107.28	121.18	86.26
5	100.63	138.5	136.53	103.94	107.76	72.55	84.85	77.21	110.48	103.77
h	0	0	0	0	0	0	0	0	0	0

p-value	0.71	0.9	0.97	0.94	0.46	0.93	0.52	0.97	0.65	0.97
CI	93.81	74.71	97.42	87	78.67	73.29	59.06	81.44	65.8	72.41
	127.43	136.73	144.97	107.6	131.34	121.89	114.68	133.58	129.4	138.98
	(33.62)	(62.02)	(47.54)	(20.59)	(52.67)	(48.60)	(55.62)	(52.14)	(63.61)	(66.57)

Table 3.9 Sample sets of six(6) runs

	1	2	3	4	5	6	7	8	9	10
1	53.91	72.45	89.05	112.68	119.26	136.7	70.92	97.33	98.34	115.81
2	130.97	82.95	114.24	133.11	99.52	104.06	83.55	89.91	81.91	77.45
3	122.81	60.88	86.85	126.47	100.87	69.61	118.07	87.04	52.1	148.6
4	38.68	77.95	110.25	85.27	120.12	124.87	125.19	150.16	114.53	73.25
5	106.17	87.74	131.91	85.61	99.67	104.74	78.73	101.79	109.52	109.23
6	141.15	169.61	89.8	113.98	61.66	101.94	67.75	66.37	68.25	102.69
h	0	0	0	0	0	0	0	0	0	0
p-value	0.83	0.29	0.65	0.85	0.47	0.78	0.64	0.6	0.98	0.98
CI	54.2	50.83	84.67	88.36	77.94	82.87	64.78	69.39	61.79	75.55
	143.69	133.04	122.7	130.68	122.43	131.09	116.63	128.14	113.1	133.46
	(89.49)	(82.21)	(38.03)	(42.33)	(44.49)	(48.22)	(51.84)	(58.76)	(51.31)	(57.92)
	11	12	13	14	15	16	17	18	19	20
1	110.66	111.2	63.39	96.01	69.52	86.43	115.57	90.57	126.89	63.6
2	72.99	114.24	96.37	72.92	104.26	127.22	132.65	70.91	91.29	79.31
3	102.82	115.56	105.35	108.59	70.21	84.59	87.39	65.4	105.75	105.82
4	56.39	87.7	89.5	104.09	124.93	93.47	105.08	115.17	77.18	103.37
5	104.12	112.8	125.82	103.96	98.85	71.59	116.77	116.24	100.44	90.45
6	70.96	116.71	113.63	66.4	83.39	102.24	88.67	97.02	91.99	135.29
h	0	0	0	0	0	0	0	0	0	0
p-value	0.68	0.26	0.99	0.75	0.98	0.96	0.95	0.96	0.98	0.96
CI	62.9	98.21	76.31	73.22	69.18	74.24	89.22	70.03	81.3	70.38
	109.74	121.2	121.71	110.77	114.55	114.27	126.16	115.07	116.55	122.24
	(46.84)	(22.99)	(45.40)	(37.55)	(45.37)	(40.04)	(36.93)	(45.04)	(35.25)	(51.86)

In these tables, the parentheses in the confidence interval column describe the range of the interval. In Table 3.6 of three simulation runs, 11 sets of 20 have the range of confidence interval of more than 80. They are underlined and shaded. In Table 3.7 of four runs, 9 sets of 20 have the range of confidence interval of more than 80. In Table 3.8 of five runs, 1 sets of 20

have the range of confidence interval of more than 80. However, in Table 3.9 of six runs, no set of 20 is over the range of confidence interval of 80.

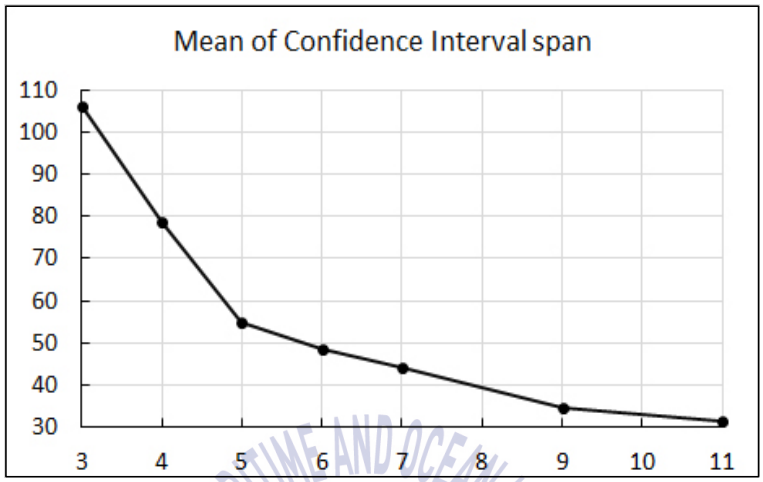


Fig. 3.4 Mean of confidence interval span of case 2

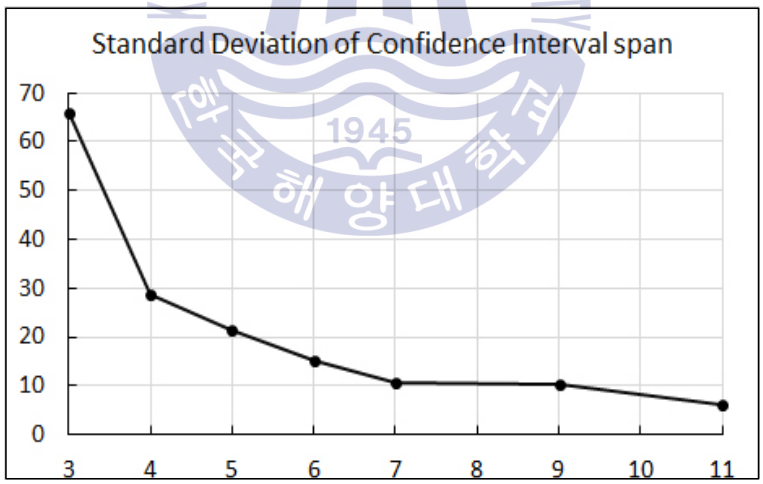


Fig. 3.5 Standard deviation of confidence interval span of case 2

As shown in Fig. 3.4, when the simulation runs are 3 and 4, the slope of the curve is very big. But after 5 the curve becomes relatively smooth. The same situation is shown in Fig. 3.5, When the simulation runs is more than 5, the curve becomes smooth. This indicates that means after 5 simulation runs the

result is beginning to stabilize.

3.2.4 Box-figures and confidence interval of case 2

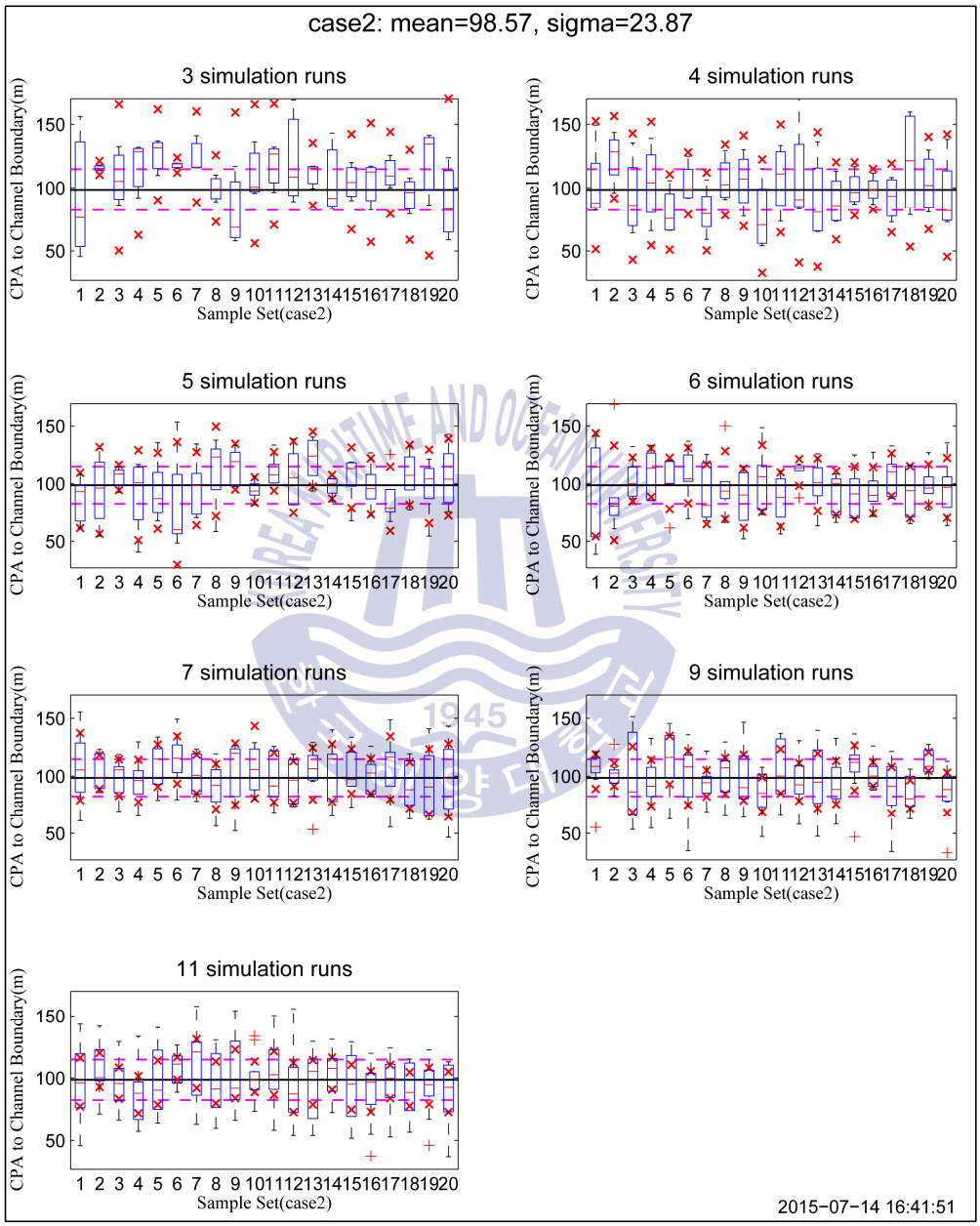


Fig. 3.6 Box-plots of case 2

As shown in Fig. 3.6, when the size of simulation runs is 3 or 4, the box interval of each box-plot fluctuates wildly, some boxes deviate from the interval [μ-0.6745σ, μ+0.6745σ] seriously, such as set 6 and set 7 in 3 simulation runs. At the same time the range of some boxes is significant, such as set 2 and set 7 in 4 simulation runs. When the simulation runs more than 5, the box of each box-plot approximates to interval [μ-0.6745σ, μ+0.6745σ] gradually.

3.2.5 Data of case 3

Case 3:

Average : μ=99.50(m)

Standard deviation : σ^2=24.33^2

Collision probability : 2.16×10^{-5}

Table 3.10 Sample sets of three(3) runs

	1	2	3	4	5	6	7	8	9	10
1	160.05	104.52	73.76	79.24	102.01	87.91	66.94	84.23	100.39	117.83
2	103.42	108.02	134.23	85.77	146.85	85.6	118.79	100.72	117.51	129.07
3	65.74	87.09	103.65	64.23	88.07	129.63	129.86	13.76	59.01	83.09
h	0	0	0	0	0	0	0	0	0	0
p	0.93	0.79	0.99	0.87	0.82	0.68	0.79	0.8	0.86	0.83
CI	-8.18	72.03	28.77	48.97	36.01	39.48	21.76	-48.5	17.59	50.45
	227.66	127.72	178.99	103.86	188.61	162.61	188.64	180.97	167.02	169.55
	(235.84)	(55.70)	(150.22)	(54.88)	(152.60)	(123.14)	(166.88)	(229.47)	(149.43)	(119.10)
	11	12	13	14	15	16	17	18	19	20
1	106.1	126.93	133.85	136.1	32.99	123.02	98.73	86.37	95.11	56.16
2	68.33	74.37	118.9	139.46	112.6	80.85	149.8	121.41	133.6	132.16
3	105.63	84.69	130.39	84.5	132.61	95.52	96.09	68.79	112.05	64.5
h	0	0	0	0	0	0	0	0	0	0
p	0.65	0.8	0.82	0.69	0.8	0.89	0.68	0.89	0.96	0.74
CI	39.52	26.15	108.27	43.49	-38.18	46.61	39.66	25.64	65.66	-19.27
	147.19	164.52	147.16	196.55	223.65	152.98	190.08	158.73	161.52	187.82
	(107.67)	(138.37)	(38.89)	(153.06)	(261.83)	(106.36)	(150.42)	(133.09)	(95.86)	(207.09)

Table 3.11 Sample sets of four(4) runs

	1	2	3	4	5	6	7	8	9	10
1	98.64	98.17	100.13	119.14	110.78	67.96	79.36	109.18	30.23	72.7
2	72.45	111.04	141.49	125.55	92.58	91.16	131.8	105.6	103.3	58.32
3	83.44	107.12	83.23	113.09	62.54	110.33	70.05	116.42	65.99	89.66
4	106.96	85.18	74.66	71.5	81.7	113.24	93.96	125.78	88.75	143.57
h	0	0	0	0	0	0	0	0	0	0
p	0.94	0.93	0.91	0.63	0.98	0.89	0.91	0.93	0.94	0.87
CI	65.85	82.12	52.63	68.46	54.78	62.4	50.54	100.07	21.41	31.75
	114.9	118.63	147.12	146.17	119.02	128.94	137.04	128.42	122.73	150.38
	(49.05)	(36.51)	(94.49)	(77.71)	(64.25)	(66.54)	(86.50)	(28.36)	(101.32)	(118.63)
	11	12	13	14	15	16	17	18	19	20
1	106.98	65.16	101.04	158.71	118.08	125.98	100.6	71.36	129.24	66.76
2	107.64	104.4	90.85	95.63	107.49	90.37	110.43	60.77	154.54	114.57
3	102.13	104.86	161.45	73.94	91.96	91.17	164.09	78.38	100.66	124.5
4	66.07	145.43	116.39	110.77	78.34	91.85	88.06	118.95	68.29	83.15
h	0	0	0	0	0	0	0	0	0	0
p	0.51	0.9	0.87	0.91	0.95	0.36	0.73	0.73	0.97	0.91
CI	64.03	52.81	67.84	52.54	71.21	72.1	62.53	41.88	54.07	54.45
	127.38	157.11	167.02	166.99	126.72	127.59	169.05	122.84	172.3	140.05
	(63.36)	(104.30)	(99.18)	(114.45)	(55.50)	(55.49)	(106.52)	(80.96)	(118.23)	(85.60)

Table 3.12 Sample sets of five(5) runs

	1	2	3	4	5	6	7	8	9	10
1	93.31	116.7	82.64	101.92	109.67	70.34	76.72	129.67	129.34	105.7
2	70.4	115.38	108.57	81.59	105.04	108.31	98.9	114.64	31.83	100.79
3	95.57	137.92	81.62	97.39	121.31	85.93	98.75	105.27	98.57	89.57
4	120.45	74.63	100.27	114.21	114.68	137.09	115.63	75.85	70.68	110.57
5	121.52	80.81	82.42	110.76	110.34	105.51	86.03	80.58	64.08	139.11
h	0	0	0	0	0	0	0	0	0	0
p-value	0.91	0.84	0.47	0.97	0.93	0.96	0.96	0.93	0.97	0.78
CI	73.75	72.03	75.57	85.22	104.6	70.13	76.91	72.92	33.13	86.21
	126.74	138.15	106.64	117.13	119.82	132.74	113.51	129.48	124.67	132.08
	(52.99)	(66.12)	(31.07)	(31.91)	(15.22)	(62.61)	(36.60)	(56.56)	(91.53)	(45.87)
	11	12	13	14	15	16	17	18	19	20
1	97.14	133.67	128.81	87.44	84.18	148.89	92.22	71.73	102.47	87.29
2	109.98	102.19	73.08	78.46	85.39	149.06	126.81	124.58	113.52	75.06

3	100.81	91.08	133.6	109.12	110.81	88.8	99.02	122.61	102.85	85
4	82.62	122.28	71.56	138.49	100.66	83.91	79.58	121.1	34.34	123.01
5	96.12	89.59	130.64	65.56	141.91	126.64	92.62	106.09	84.17	87.64
h	0	0	0	0	0	0	0	0	0	0
p-value	0.84	0.94	0.49	0.94	0.96	0.89	0.75	0.65	0.73	0.35
CI	85.07	83.55	67.56	60.23	75.26	80.21	76.25	81.65	48.33	68.89
	109.59	131.98	147.52	131.39	133.92	158.71	119.85	136.79	126.61	114.31
	(24.52)	(48.43)	(79.96)	(71.16)	(58.66)	(78.51)	(43.60)	(55.14)	(78.27)	(45.42)

Table 3.13 Sample sets of six(6) runs

	1	2	3	4	5	6	7	8	9	10
1	110.21	102.51	112.23	63.34	120.37	102.86	82.44	84.47	77.7	96.88
2	80.19	138.46	106.57	104.75	71.49	95.08	139.1	94.77	146.6	127.09
3	79.94	71.39	134.4	89.52	113.3	116.18	97.15	86.68	87.63	81.59
4	110.94	115.66	109.16	96.4	70.08	133.8	96.46	101.16	79.45	131.22
5	91.65	135.4	87.19	85.18	116.3	53.65	62.8	74.27	97.38	76.96
6	104.91	95.49	74.9	102.77	114.02	72.25	110.66	129.5	108.8	105.04
h	0	0	0	0	0	0	0	0	0	0
p-value	0.86	0.97	0.89	0.93	0.31	0.99	0.97	0.91	0.93	0.95
CI	81.24	83.09	82.29	74.37	76.29	65.07	71.01	75.02	72.52	79.41
	111.37	136.55	125.86	106.28	125.57	126.2	125.2	115.26	126.66	126.85
	(30.13)	(53.46)	(43.57)	(31.91)	(49.28)	(61.13)	(54.20)	(40.24)	(54.14)	(47.44)
	11	12	13	14	15	16	17	18	19	20
1	62.28	96.28	70.19	86.52	105.26	65.53	112.7	69.93	98.43	52.6
2	108.82	104.52	105.14	109.21	86.45	116.22	106.2	80.88	144.93	89.66
3	89.16	110.59	66.5	83.13	115.46	115.89	63.37	58.8	124.57	130.82
4	98.14	90.68	130.76	94.46	44.77	96.9	76.5	101.88	103.53	157.8
5	71.95	41.68	113.68	100.85	71.13	130.51	56.55	103.41	111.84	100.75
6	109.08	55.21	128.2	112.98	122.84	49.82	117.99	120.41	87.27	116.4
h	0	0	0	0	0	0	0	0	0	0
p-value	0.98	0.68	0.91	0.99	0.96	0.82	0.8	0.92	0.98	0.99
CI	69.56	53.71	72.99	85.23	59.97	62.44	60.87	64.82	90.21	70.08
	110.25	112.61	131.84	110.48	122	129.19	116.9	113.61	133.31	145.93
	(40.69)	(58.91)	(58.85)	(25.25)	(62.04)	(66.75)	(56.04)	(48.79)	(43.10)	(75.85)

In these tables, the parentheses in the confidence interval column describe the range of the interval. In Table 3.10 of three simulation runs, 16 sets of 20

have the range of confidence interval of more than 100. They are underlined and shaded. In Table 3.11 of four runs, 6 sets of 20 have the range of confidence interval of more than 100. However, in Table 3.12 of five runs and Table 3.13 of six runs, no set of 20 is over the range of confidence interval of 100.

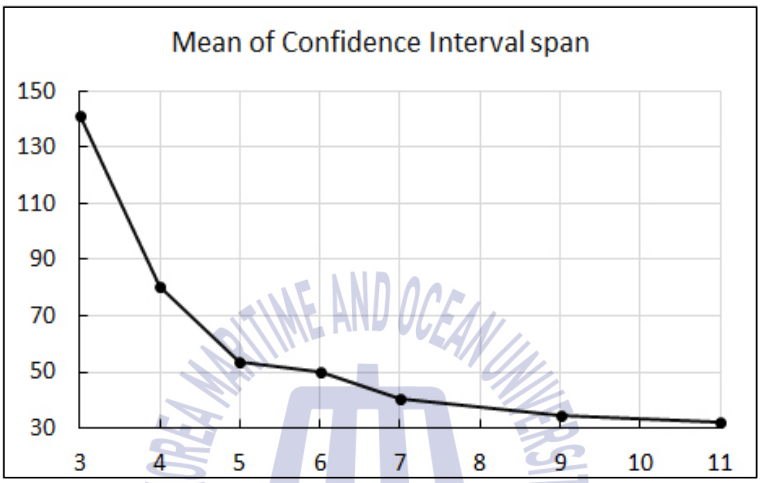


Fig. 3.7 Mean of confidence interval span of case 3

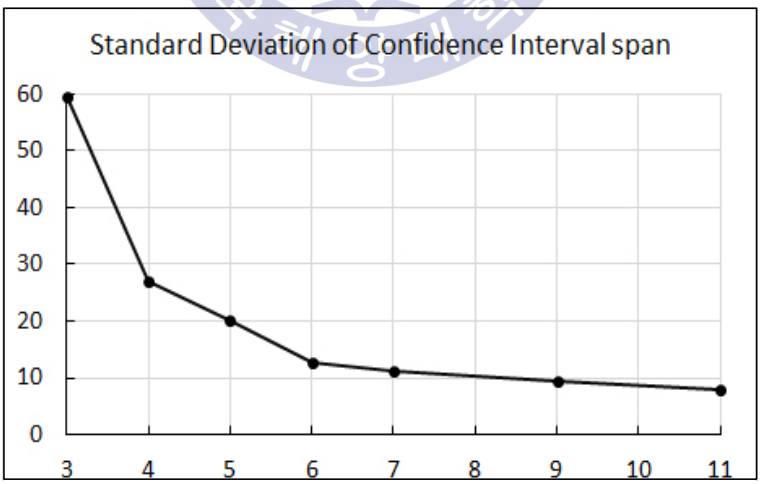


Fig. 3.8 Standard deviation of confidence interval span of case 3

As shown in Fig. 3.7, when the simulation runs are 3 and 4, the slope of the

curve is very big. But after 5 the curve becomes relatively smooth. The same situation is shown in Fig. 3.8, When the simulation runs is more than 5, the curve becomes smooth. This indicates that after 5 simulation runs the result is beginning to stabilize.

3.2.6 Box-figures and confidence interval of case 3

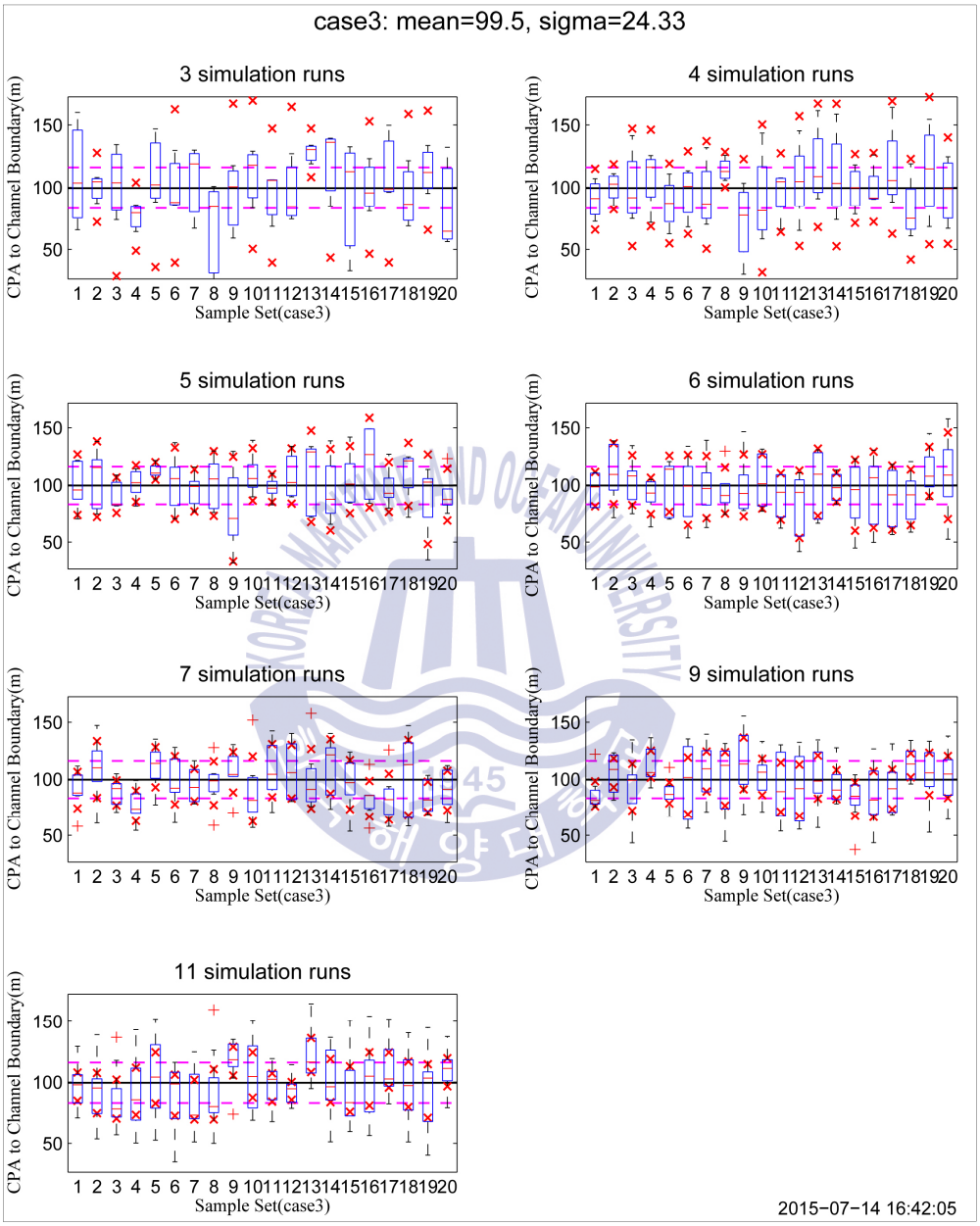


Fig. 3.9 Box-plots of case 3

As shown in Fig. 3.9, when the size of simulation runs is 3 or 4, the box interval of each box-plot fluctuates wildly, some boxes deviate from the

interval [μ-0.6745σ, μ+0.6745σ] seriously, such as set 4 and set 13 in 3 simulation runs. At the same time the range of some boxes is significant, such as set 8 and set 19 in 4 simulation runs. When the simulation runs more than 5, the box of each box-plot approximates to interval [μ-0.6745σ, μ+0.6745σ] gradually.

3.2.7 Data of case 4

Case 4:

Average : μ=99.34(m)

Standard deviation : σ^2=21.48^2

Collision probability : 1.88×10^{-6}

Table 3.14 Sample sets of three(3) runs

	1	2	3	4	5	6	7	8	9	10
1	141.72	99.78	89.65	106.89	112.79	100.68	95.11	100.13	110.25	105.66
2	134.7	62.35	99.14	89.76	137.69	121.1	95.68	112.78	93.07	102.49
3	94.19	131.4	101.48	121.22	98.75	95.49	121.75	80.07	127.15	114.53
h	0	0	0	0	0	0	0	0	0	0
p	0.77	0.97	0.8	0.97	0.9	0.81	0.65	0.92	0.99	0.84
CI	59.8	11.96	81.19	66.84	67.42	72.12	66.37	56.69	67.82	92.05
	187.27	183.72	112.32	145.08	165.41	139.4	141.99	138.63	152.5	123.07
	(127.47)	(171.75)	(31.12)	(78.24)	(97.99)	(67.28)	(75.62)	(81.94)	(84.68)	(31.02)
	11	12	13	14	15	16	17	18	19	20
1	147.76	103.09	91.44	55.64	78.65	89.73	73.62	115.45	89.98	110.48
2	132.22	113.06	100.15	122.86	123.67	64.33	89.39	90.73	103.35	142.78
3	109.11	109.61	94.25	67.9	119.43	68.61	36.46	96.37	97.72	56.7
h	0	0	0	0	0	0	0	0	0	0
p	0.93	0.89	0.88	0.79	0.72	0.79	0.86	0.82	0.94	0.91
CI	81.39	96.02	84.24	-6.79	45.51	40.44	-1.01	68.67	80.34	-4.71
	178	121.15	106.32	171.06	168.99	108	134	133.03	113.69	211.34
	(96.61)	(25.14)	(22.08)	(177.84)	(123.49)	(67.56)	(135.01)	(64.37)	(33.35)	(216.05)

Table 3.15 Sample sets of four(4) runs

	1	2	3	4	5	6	7	8	9	10
1	110.84	72.84	130.9	109.77	101.6	136.45	110.47	88.77	75.59	76.27
2	70.06	82.45	63.46	88.98	85.71	120.41	107.44	106.08	87.54	70.02
3	140.73	88.43	94.28	125.04	78.85	138.66	87.88	125.51	71.42	123.67
4	99.57	69.09	61.73	78.71	119.2	107.51	118.72	100.96	111.26	62.77
h	0	0	0	0	0	0	0	0	0	0
p	0.96	0.92	0.85	0.93	0.93	0.86	0.8	0.92	0.92	0.61
CI	58.81	64.13	35.85	67.56	67.75	102.48	85.34	81.01	57.98	39.34
	151.79	92.27	139.33	133.69	124.94	149.04	126.91	129.65	114.92	127.02
	(92.98)	(28.13)	(103.48)	(66.14)	(57.19)	(46.56)	(41.57)	(48.64)	(56.94)	(87.67)
	11	12	13	14	15	16	17	18	19	20
1	117.6	83.15	111.14	100.04	92.54	95.24	46.1	85.31	55.66	98.65
2	103.31	98.26	80.02	142.88	92.01	95.82	111.84	134.14	82.96	83.48
3	99.29	127.93	116.01	90.13	108	119.74	100.66	103.08	112.08	92.35
4	75.52	76.42	95.76	131.56	68.04	111.75	106.9	119.74	96.89	67.98
h	0	0	0	0	0	0	0	0	0	0
p	0.89	0.93	0.91	0.91	0.79	0.8	0.54	0.97	0.96	0.95
CI	71.12	60.01	74.82	76.23	63.89	86.35	42.8	77.02	48.74	64.44
	126.74	132.87	126.64	156.08	116.4	124.92	139.95	144.12	125.05	106.79
	(55.61)	(72.86)	(51.82)	(79.85)	(52.51)	(38.58)	(97.15)	(67.10)	(76.32)	(42.34)

Table 3.16 Sample sets of five(5) runs

	1	2	3	4	5	6	7	8	9	10
1	122.21	111.06	96.74	91.15	67.38	120.48	95.8	108.69	112.57	125.91
2	94.97	101.88	100.7	102.81	80.86	100.79	132.6	132.12	98.06	106.27
3	132.09	71.54	133.48	112.18	85.94	120.21	70.1	92.46	76.3	67.8
4	120.05	78.85	98.74	90.51	90.16	97.2	86.22	124.38	121.74	84.85
5	103.71	96.11	107.39	85.62	75.17	83.99	65.78	96.4	66.48	107.82
h	0	0	0	0	0	0	0	0	0	0
p-value	0.87	0.96	0.66	0.71	0.98	0.87	0.93	0.96	0.97	0.89
CI	96.01	71.58	88.64	83.01	68.76	85	56.98	89.42	65.94	70.58
	133.21	112.19	126.18	109.9	91.04	124.07	123.22	132.2	124.13	126.48
	(37.20)	(40.61)	(37.54)	(26.88)	(22.28)	(39.07)	(66.24)	(42.78)	(58.19)	(55.90)
	11	12	13	14	15	16	17	18	19	20
1	94.95	100.65	83.03	84.21	111.99	83.81	136.55	125.05	95.2	114.51
2	76.51	85.12	97.22	110.94	107.56	119.32	92.81	98.72	64.84	90.11
3	95.18	122.68	88.59	98.41	96.55	124.5	95	119.18	111.23	63.38

4	84.98	59.47	119.35	137.05	105.6	108	115.91	80.73	127.93	116.92
5	90.6	91.56	99.42	111.93	90.43	90.33	117.94	123.16	118.11	89.85
h	0	0	0	0	0	0	0	0	0	0
p-value	0.95	0.97	0.86	0.9	0.87	0.96	0.92	0.68	0.92	0.94
CI	78.69	63.3	80.29	84.26	91.56	83.17	89.17	85.59	72.84	67.81
	98.2	120.5	114.75	132.75	113.29	127.21	134.12	133.14	134.09	122.1
	(19.50)	(57.19)	(34.46)	(48.49)	(21.74)	(44.04)	(44.94)	(47.55)	(61.25)	(54.28)

Table 3.17 Sample sets of six(6) runs

	1	2	3	4	5	6	7	8	9	10
1	112.38	127.41	153.77	85.85	87.69	95.39	84.83	141.73	83.23	75.63
2	93.81	82.43	109.65	93	115.49	71.7	90.85	82.6	67.62	76.57
3	72.51	124.18	106.53	79.81	123.46	96.72	92.58	99.08	99.57	88.13
4	116.33	82.29	95.58	108.34	123.69	98.41	84.11	84.52	101.43	147.2
5	96.68	67.92	110.47	90.49	152.82	97.17	117.71	104.53	109.16	85.41
6	80.94	111.52	100.25	109.12	139.58	81.76	64.58	109.08	130.22	102.48
h	0	0	0	0	0	0	0	0	0	0
p-value	0.98	0.77	0.29	0.9	0.96	0.37	0.76	0.84	0.96	0.64
CI	77.49	73.09	90.76	81.89	100.49	78.71	71.07	81.03	75.95	67.63
	113.4	125.49	134.66	106.98	147.09	101.68	107.15	126.15	121.12	124.18
	(35.91)	(52.40)	(43.90)	(25.09)	(46.60)	(22.97)	(36.09)	(45.12)	(45.17)	(56.55)
	11	12	13	14	15	16	17	18	19	20
1	76.29	112	82.12	102.83	82.99	106.54	81.87	91.02	76.49	89
2	112.03	89	65.91	118.4	116.46	140.27	93.1	73.56	73.05	122.2
3	123.44	56.53	70.98	98.55	96.68	133.6	104.3	103.28	109.11	98.96
4	124.6	115.45	126.95	93.11	105.45	108.51	110.4	117.88	99.57	98.73
5	110.52	109.18	94.39	84.38	113.22	109.24	123.87	113.02	131.85	97.7
6	91	89.51	93.52	114.96	110.26	88.56	90.73	59.66	61.78	147.7
h	0	0	0	0	0	0	0	0	0	0
p-value	0.75	0.83	0.83	0.98	0.91	0.67	0.95	0.98	0.87	0.39
CI	86.32	72.03	66.01	88.45	91.1	94.38	84.76	69.05	64.41	86.03
	126.3	118.53	111.95	115.63	117.25	134.52	116.66	117.09	119.54	132.07
	(39.98)	(46.50)	(45.94)	(27.18)	(26.15)	(40.14)	(31.91)	(48.04)	(55.14)	(46.04)

In these tables, the parentheses in the confidence interval column describe the range of the interval. In Table 3.14 of three simulation runs, 14 sets of 20

have the range of confidence interval of more than 60. They are underlined and shaded. In Table 3.15 of four runs, 9 sets of 20 have the range of confidence interval of more than 60. However, in Table 3.16 of five runs and Table 3.17 of six runs, no set of 20 is over the range of confidence interval of 60.

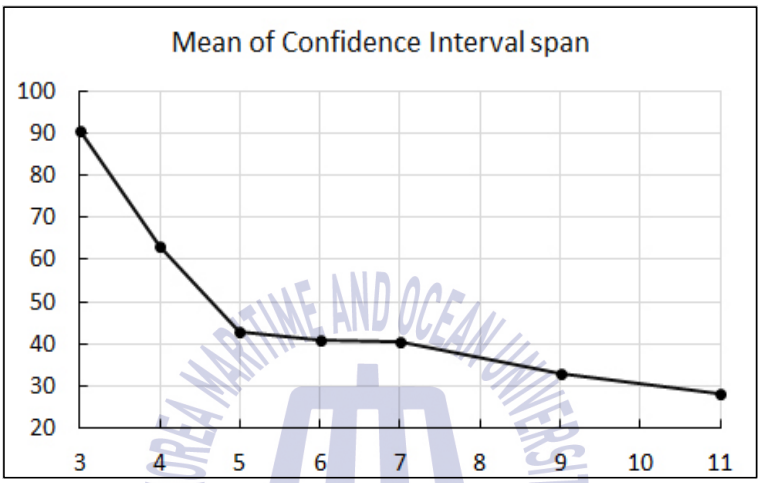


Fig. 3.10 Mean of confidence interval span of case 4

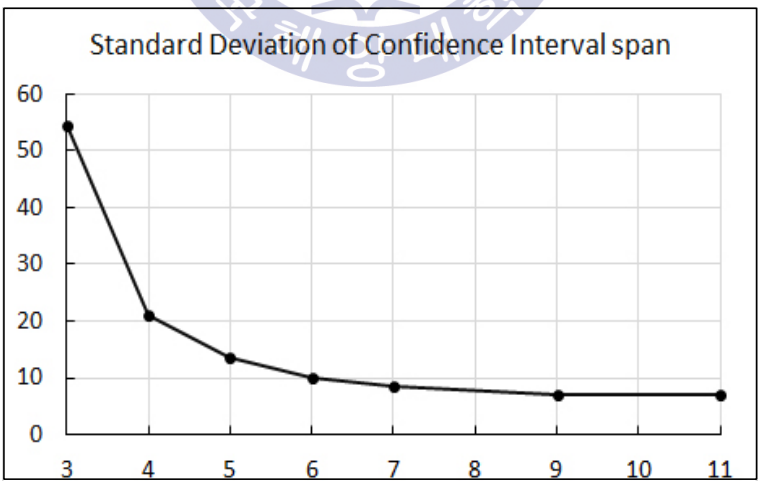


Fig. 3.11 Standard deviation of confidence interval span of case 4

As shown in Fig. 3.10, when the simulation runs are 3 and 4, the slope of

the curve is very big. But after 5 the curve becomes relatively smooth. The same situation is shown in Fig. 3.11, When the simulation runs is more than 5, the curve becomes smooth. This indicates that after 5 simulation runs the result is beginning to stabilize.

3.2.8 Box-figures and confidence interval of case 4

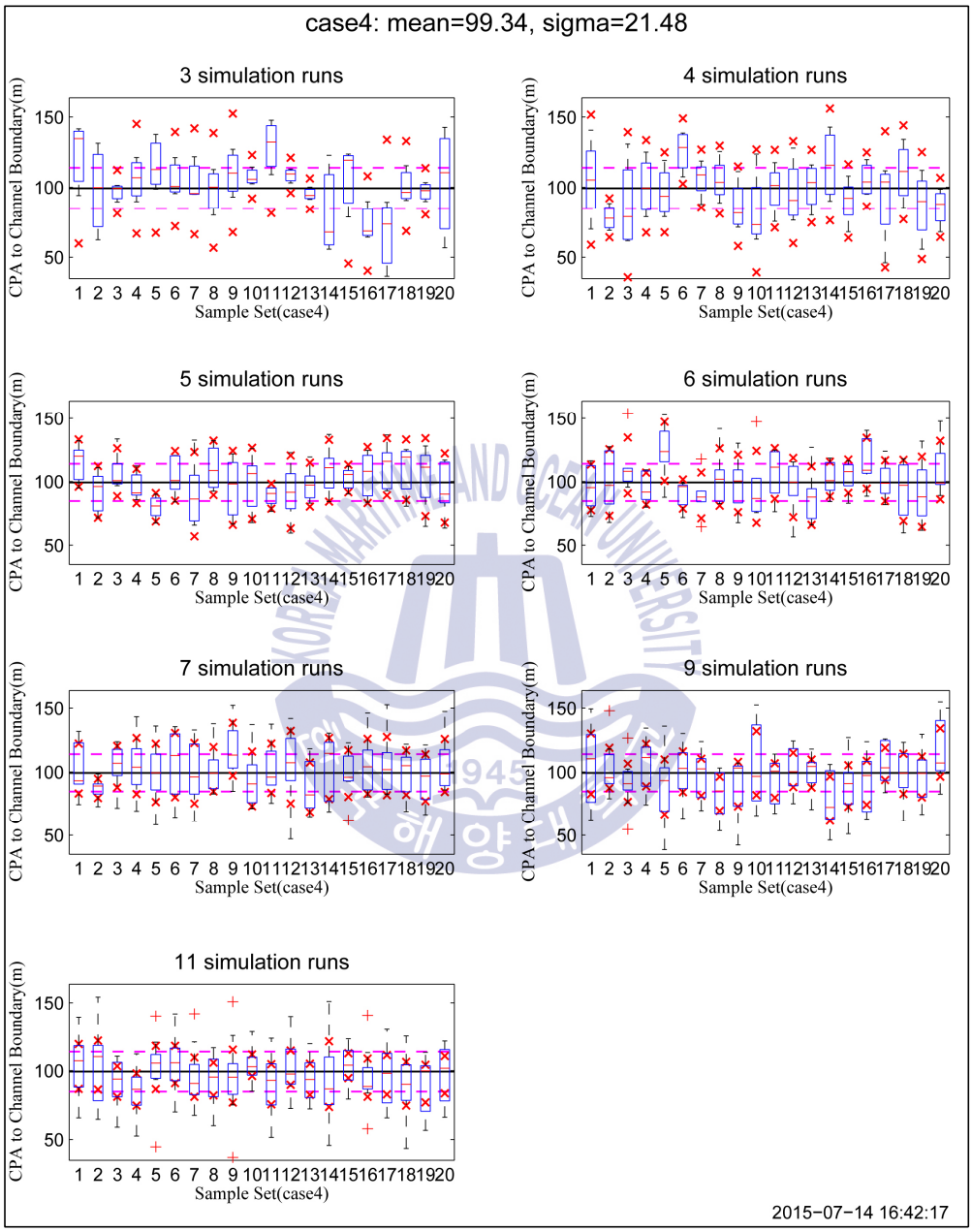


Fig. 3.12 Box-plots of case 4

As shown in Fig. 3.12, when the size of simulation runs is 3 or 4, the box

interval of each box-plot fluctuates wildly, some boxes deviate from the interval [μ-0.6745σ, μ+0.6745σ] seriously, such as set 11 and set 7 in 3 simulation runs. At the same time the range of some boxes is significant, such as set 2 and set 3 in 4 simulation runs. When the simulation runs more than 5, the box of each box-plot approximates to interval [μ-0.6745σ, μ+0.6745σ] gradually.

3.2.9 Data of case 5

Case 5:

Average : μ=83.72(m)

Standard deviation : σ^2=18.62^2

Collision probability : 3.46×10^{-6}

Table 3.18 Sample sets of three(3) runs

	1	2	3	4	5	6	7	8	9	10
1	110.48	108.10	84.44	53.51	84.83	63.03	68.34	76.67	71.53	85.03
2	100.27	36.96	84.43	65.72	94.69	83.44	110.93	85.44	48.60	61.18
3	104.70	92.48	70.23	90.66	98.28	93.12	100.08	95.28	91.72	109.13
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.95	0.81	0.64	0.88	0.84	0.88	0.84	0.98	0.98	0.99
CI	92.44	(13.71)	59.32	22.94	75.30	41.71	38.14	62.67	17.03	25.56
	117.86	172.07	100.08	116.99	109.89	118.02	148.09	108.92	124.21	144.67
	(25.43)	(185.77)	(40.76)	(94.05)	(34.59)	(76.31)	(109.95)	(46.25)	(107.18)	(119.11)
	11	12	13	14	15	16	17	18	19	20
1	93.48	85.56	75.74	64.77	97.17	106.31	100.25	51.20	91.97	39.28
2	82.77	72.35	90.19	108.92	43.71	90.04	85.38	100.59	46.55	89.65
3	94.33	51.81	65.38	96.42	73.46	45.65	103.32	75.77	93.59	83.83
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.70	0.92	0.94	0.85	0.96	0.84	0.79	0.99	0.67	0.74
CI	74.20	27.67	46.15	33.51	4.92	2.67	72.49	14.51	11.04	2.47
	106.19	112.15	108.05	146.56	137.98	158.66	120.14	137.19	143.70	139.37
	(31.99)	(84.49)	(61.90)	(113.04)	(133.06)	(155.99)	(47.66)	(122.68)	(132.67)	(136.90)

Table 3.19 Sample sets of four(4) runs

	1	2	3	4	5	6	7	8	9	10
1	84.91	87.35	56.82	110.53	96.15	83.60	69.88	84.78	93.05	70.54
2	99.75	109.68	113.47	87.95	120.29	91.60	70.67	65.65	92.03	81.37
3	76.23	75.01	97.07	70.97	96.89	78.31	63.65	78.16	80.82	41.29
4	76.09	70.45	91.52	76.79	78.86	54.92	73.92	99.98	93.04	89.64
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.87	0.92	0.83	0.93	0.84	0.83	0.82	0.96	0.44	0.91
CI	66.53	57.69	51.80	58.77	70.98	52.02	62.71	59.40	80.25	37.11
	101.96	113.56	127.64	114.35	125.11	102.20	76.35	104.89	99.23	104.31
	(35.42)	(55.86)	(75.84)	(55.58)	(54.13)	(50.19)	(13.65)	(45.49)	(18.98)	(67.21)
	11	12	13	14	15	16	17	18	19	20
1	46.37	112.82	84.50	103.02	92.21	54.71	30.83	77.43	45.99	49.84
2	69.69	63.41	81.90	90.71	100.38	118.17	129.59	89.42	83.20	89.80
3	108.10	69.50	98.18	88.77	109.05	73.37	62.00	64.00	85.69	65.93
4	114.84	81.15	83.93	74.94	94.36	96.85	70.62	102.16	77.97	95.94
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.87	0.88	0.48	0.92	0.92	0.96	0.84	0.98	0.60	0.91
CI	33.18	46.71	75.28	71.06	87.00	41.80	7.60	57.27	43.89	41.34
	136.32	116.73	98.98	107.66	111.00	129.75	138.91	109.24	102.54	109.41
	(103.13)	(70.02)	(23.71)	(36.60)	(24.00)	(87.95)	(131.31)	(51.97)	(58.65)	(68.07)

Table 3.20 Sample sets of five(5) runs

	1	2	3	4	5	6	7	8	9	10
1	79.30	79.16	75.76	104.37	80.76	81.88	87.25	81.65	69.42	72.94
2	98.87	96.72	76.05	59.27	96.33	103.45	57.96	87.89	63.12	79.30
3	97.06	66.98	73.36	86.17	65.69	92.36	69.11	92.91	89.84	103.55
4	88.56	81.05	93.76	91.06	83.13	71.18	64.79	92.43	71.54	72.36
5	88.25	81.55	110.84	67.69	100.81	111.21	40.58	92.12	86.03	36.50
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.96	0.73	0.54	0.96	0.97	0.98	0.97	0.60	0.84	0.70
CI	80.64	67.96	65.93	59.15	68.10	72.04	42.86	83.47	61.82	43.12
	100.17	94.22	105.98	104.28	102.59	112.00	85.01	95.33	90.16	102.74
	(19.53)	(26.26)	(40.06)	(45.13)	(34.50)	(39.96)	(42.15)	(11.87)	(28.35)	(59.62)
	11	12	13	14	15	16	17	18	19	20
1	76.50	93.47	72.91	82.94	77.28	98.30	103.12	49.39	69.41	86.34
2	87.06	95.20	85.67	72.97	67.47	64.62	76.12	77.70	77.15	86.95

3	104.50	104.10	108.00	96.47	95.47	94.07	61.89	51.31	77.41	70.52
4	77.69	67.25	74.31	65.06	101.89	67.76	84.60	80.76	85.25	150.39
5	83.47	93.94	112.27	75.26	71.46	67.66	65.16	39.12	61.27	105.81
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.82	0.38	0.91	0.95	0.87	0.49	0.97	0.76	0.90	0.80
CI	71.84	73.59	67.61	63.79	63.89	58.27	57.57	36.69	62.80	61.74
	99.85	108.00	113.65	93.29	101.54	98.70	98.79	82.62	85.40	138.27
	(28.02)	(34.41)	(46.04)	(29.50)	(37.65)	(40.43)	(41.23)	(45.92)	(22.60)	(76.53)

Table 3.21 Sample sets of six(6) runs

	1	2	3	4	5	6	7	8	9	10
1	100.95	68.68	90.71	100.85	87.51	72.15	66.85	72.40	91.99	78.23
2	83.98	87.83	57.27	83.73	147.19	79.13	77.49	85.08	58.91	81.84
3	49.02	98.75	106.10	81.35	82.37	81.31	78.40	91.78	88.29	72.11
4	67.73	77.74	82.96	71.31	72.13	87.81	78.12	108.65	75.94	96.30
5	72.53	60.02	70.74	89.36	98.70	93.00	109.45	87.23	52.11	86.71
6	88.42	86.52	75.17	64.48	70.19	85.62	128.07	80.97	72.27	60.11
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.99	0.97	0.99	0.99	0.75	0.99	0.36	0.93	0.99	0.99
CI	58.09	65.17	62.75	68.29	63.08	75.52	64.92	74.90	56.74	66.18
	96.12	94.67	98.23	95.40	122.95	90.82	114.55	100.47	89.77	92.25
	(38.03)	(29.50)	(35.48)	(27.11)	(59.87)	(15.29)	(49.63)	(25.56)	(33.03)	(26.07)
	11	12	13	14	15	16	17	18	19	20
1	58.46	81.37	100.55	88.95	83.63	63.36	58.16	62.32	114.88	77.56
2	99.28	84.91	99.97	95.56	76.96	86.60	81.54	93.26	69.82	98.51
3	95.57	111.66	95.46	96.01	79.39	65.62	88.23	109.02	102.86	77.64
4	68.86	110.34	92.18	55.95	67.12	87.67	69.13	84.39	77.09	57.20
5	65.13	70.15	77.36	75.36	103.66	79.98	83.61	50.11	68.77	75.93
6	78.96	98.07	71.63	92.38	79.07	100.06	93.90	76.75	84.74	61.51
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.93	0.96	0.76	0.60	0.69	0.95	0.81	0.99	0.93	0.75
CI	60.20	75.21	76.75	67.55	68.93	65.81	65.28	57.04	66.69	59.40
	95.23	110.30	102.30	100.52	94.35	95.29	92.91	101.57	106.03	90.05
	(35.03)	(35.09)	(25.55)	(32.98)	(25.42)	(29.48)	(27.63)	(44.53)	(39.35)	(30.64)

In these tables, the parentheses in the confidence interval column describe the range of the interval. In Table 3.18 of three simulation runs, 14 sets of 20

have the range of confidence interval of more than 60. They are underlined and shaded. In Table 3.19 of four runs, 7 sets of 20 have the range of confidence interval of more than 60. In Table 3.20 of five runs, 1 set of 20 has the range of confidence interval of more than 60. However, in Table 3.21 of six runs, no set of 20 is over the range of confidence interval of 60.

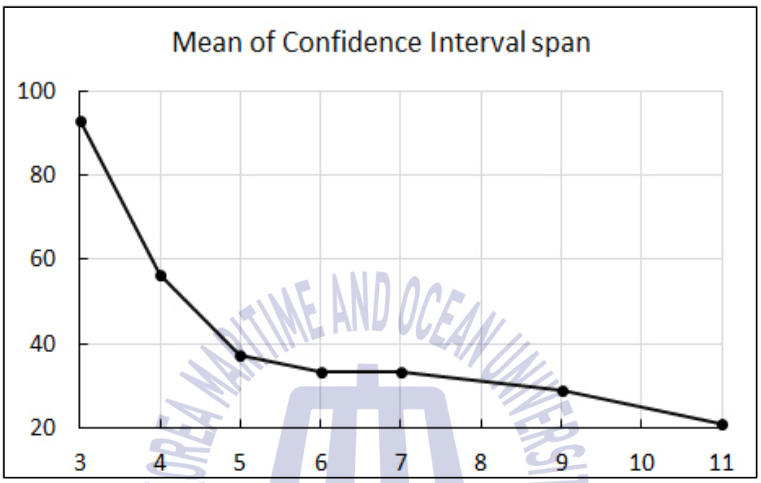


Fig. 3.13 Mean of confidence interval span of case 5

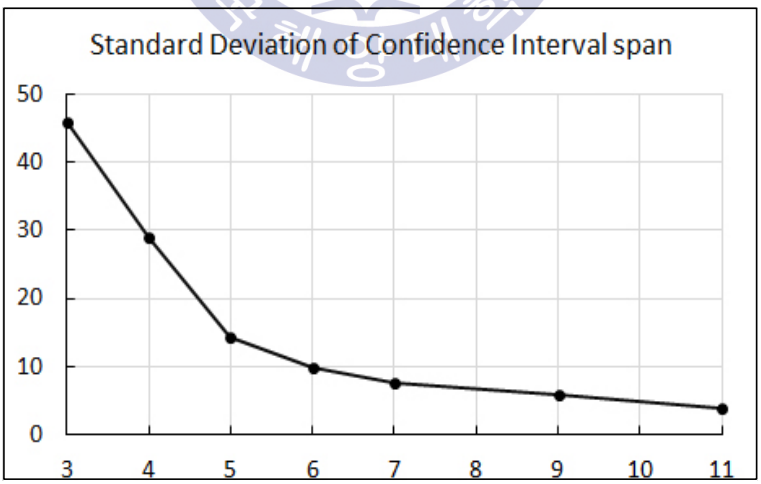


Fig. 3.14 Standard deviation of confidence interval span of case 5

As shown in Fig. 3.13, when the simulation runs are 3 and 4, the slope of

the curve is very big. But after 5 the curve becomes relatively smooth. The same situation is shown in Fig. 3.14, When the simulation runs is more than 5, the curve becomes smooth. This indicates that after 5 simulation runs the result is beginning to stabilize.

3.2.10 Box-figures and confidence interval of case 5

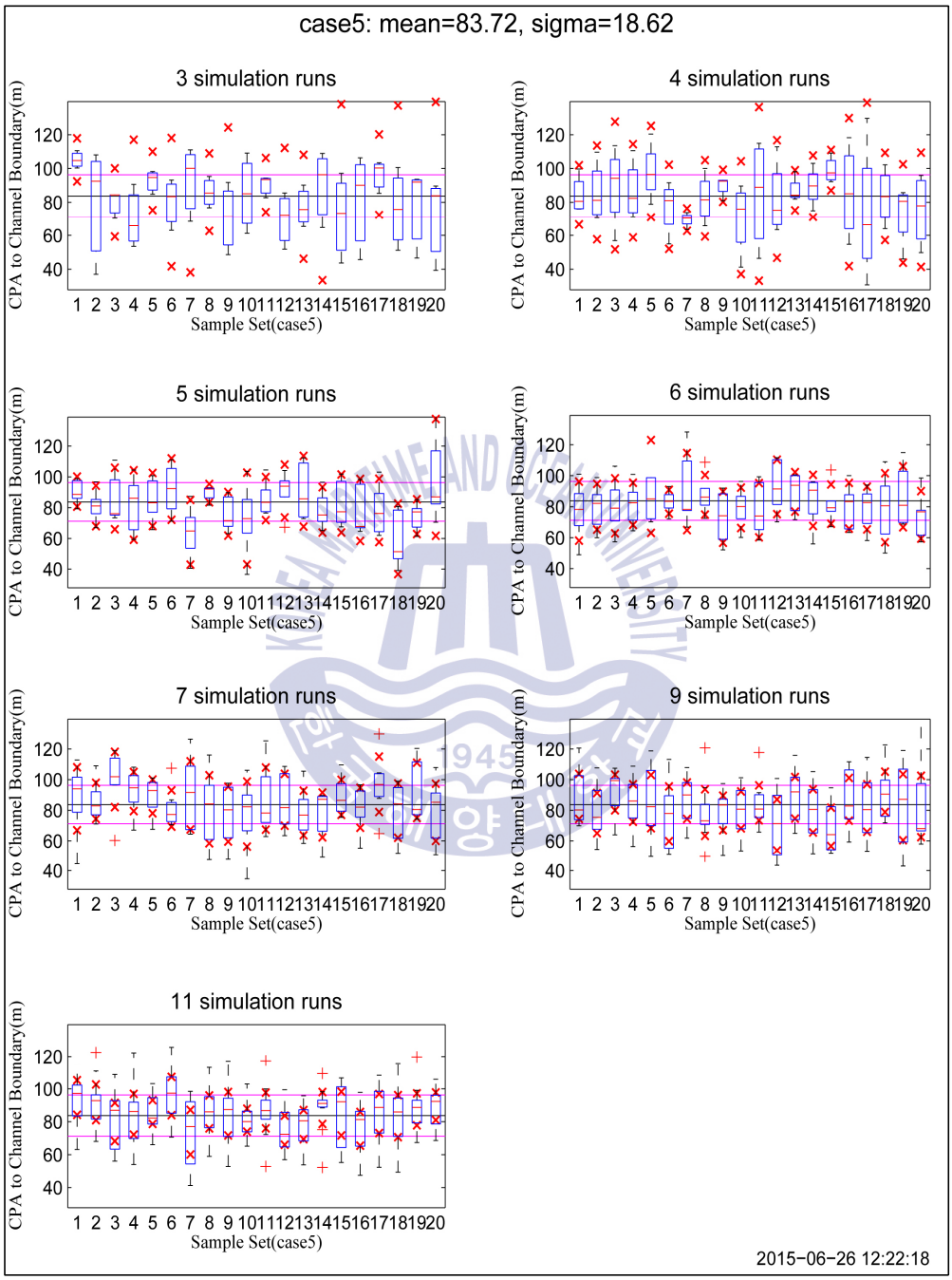


Fig. 3.15 Box-plots of case 5

As shown in Fig. 3.15, when the size of simulation runs is 3 or 4, the box interval of each box-plot fluctuates wildly, some boxes deviate from the interval [μ-0.6745σ, μ+0.6745σ] seriously, such as set 1 and set 17 in 3 simulation runs. At the same time the range of some boxes is significant, such as set 7 and set 17 in 4 simulation runs. When the simulation runs more than 5, the box of each box-plot approximates to interval [μ-0.6745σ, μ+0.6745σ] gradually.

4. Generation and analysis of random sample sets with less than collision probability of 10^{-8}

In chapter 3, the data of 5 cases are generated with parameters of mean and standard deviation. After analysing the box-plots and the confidence interval span of each case, it indicates that a relatively better result can be obtained when the sample size is larger than 5. In order to make sure if the same result can be obtain when the collision probability is smaller than 10^{-8}, this chapter generates other 5 cases data, then analyses them by the same methods as in chapter 3.

4.1 Determination of parameters for generation of random sample set

At first, this chapter generates the random sample set case 6, case 7, case 8, case 9,case 10. At the same time the collision or grounding probability is less than 10^{-8}. The following table indicates 5 cases which are also obtained from the latest maritime traffic safety assessment.

Table 4.1 The mean and standard deviation of each case

Case	Mean	Standard Deviation	Collision Probability
6	102.32	18.81	2.67×10^{-8}
7	90.54	16.39	1.66×10^{-8}
8	90.66	16.85	3.72×10^{-8}
9	104.36	17.89	2.72×10^{-9}
10	107.94	19.22	9.77×10^{-9}

Using the above parameters, the paper generates 5 cases of sample sets randomly. Each case of sample sets is with the size of 3, 4, 5, 6, 7, 9, and 11. Each random sample set will be composed of 20 simulation sets. Each sample set is tested by KS test and t-test. And the confidence interval of each sample

set is also calculated.

4.2 Generation and analysis of random sample set from case 6 to case 10

4.2.1 Data of case 6

Case 6:

Average : μ=102.32(m)

Standard deviation : σ^2=18.81^2

Collision probability : 2.67×10^{-8}

Table 4.2 Sample sets of three(3) runs

	1	2	3	4	5	6	7	8	9	10
1	120.77	82.60	125.91	116.30	81.99	101.99	91.20	112.18	70.09	117.92
2	103.69	104.06	88.63	122.95	94.45	71.46	116.78	89.96	127.21	80.81
3	100.28	112.94	111.39	99.83	87.45	89.91	120.74	91.36	67.63	103.32
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.79	0.86	0.92	0.86	0.96	0.93	0.76	0.69	0.67	0.93
CI	80.97	61.11	61.97	83.46	72.45	49.59	69.74	66.92	4.57	54.24
	135.52	138.62	155.32	142.60	103.47	125.98	149.40	128.75	172.06	147.12
	(54.55)	(77.51)	(93.35)	(59.15)	(31.02)	(76.39)	(79.66)	(61.83)	(167.49)	(92.88)
	11	12	13	14	15	16	17	18	19	20
1	97.96	97.52	76.98	105.18	125.28	82.73	103.96	87.90	72.41	94.50
2	117.13	127.33	114.55	71.38	105.19	98.32	102.12	95.00	95.63	119.06
3	128.62	75.41	112.56	116.86	99.11	121.82	112.93	78.89	118.78	86.51
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.91	0.95	0.68	0.84	0.82	0.93	0.79	0.96	0.99	0.83
CI	76.10	35.36	48.85	39.14	75.83	52.08	91.97	67.21	38.00	57.88
	153.05	164.82	153.88	156.48	143.89	149.83	120.70	107.32	153.21	142.16
	(76.94)	(129.46)	(105.03)	(117.34)	(68.06)	(97.75)	(28.73)	(40.11)	(115.20)	(84.29)

Table 4.3 Sample sets of four(4) runs

	1	2	3	4	5	6	7	8	9	10
1	100.29	92.13	118.62	112.39	86.53	120.27	59.61	131.73	117.97	117.37
2	88.36	86.20	140.22	71.13	102.39	104.66	109.73	70.39	108.27	84.45

3	110.82	47.94	110.05	122.20	103.54	104.54	75.32	104.41	79.65	91.29
4	113.01	74.57	103.03	105.76	104.23	129.52	106.55	87.77	113.84	128.66
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.90	0.92	0.92	0.77	0.44	0.79	0.83	0.97	0.69	0.91
CI	85.14	44.04	92.30	67.53	85.70	95.16	49.01	57.04	77.38	72.04
	121.10	106.38	143.66	138.21	112.64	134.34	126.60	140.12	132.48	138.85
	(35.95)	(62.34)	(51.35)	(70.69)	(26.93)	(39.17)	(77.59)	(83.08)	(55.11)	(66.81)
	11	12	13	14	15	16	17	18	19	20
1	95.74	128.73	124.12	105.87	114.04	103.09	111.10	54.65	64.34	115.19
2	119.12	93.88	136.45	106.83	85.74	93.84	80.02	96.94	97.19	82.83
3	130.48	119.10	70.32	124.21	105.67	121.03	102.83	114.20	117.73	120.16
4	119.95	130.91	117.40	102.53	113.11	132.11	100.43	115.61	90.41	128.83
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.69	0.85	0.70	0.53	0.83	0.94	0.75	0.85	0.93	0.71
CI	92.99	91.14	66.03	94.36	83.72	85.05	77.59	50.11	57.37	79.79
	139.66	145.17	158.11	125.36	125.56	139.99	119.60	140.59	127.47	143.71
	(46.67)	(54.02)	(92.08)	(31.00)	(41.83)	(54.95)	(42.00)	(90.48)	(70.10)	(63.93)

Table 4.4 Sample sets of five(5) runs

	1	2	3	4	5	6	7	8	9	10
1	117.63	114.04	106.64	137.59	118.19	92.80	90.04	105.85	72.49	97.37
2	98.97	103.87	120.87	98.01	124.94	75.11	90.93	105.44	52.84	99.41
3	101.47	105.15	103.56	80.19	100.67	93.76	93.37	100.22	93.90	109.65
4	90.29	118.61	78.07	105.95	120.93	128.91	118.71	71.43	115.95	109.79
5	94.08	113.27	100.60	93.92	95.98	107.59	102.57	127.99	101.72	117.02
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.80	0.87	0.79	0.85	0.74	0.93	0.73	0.81	0.96	0.86
CI	87.43	103.20	82.77	76.55	96.06	74.78	84.19	77.05	56.47	96.54
	113.54	118.78	121.13	129.71	128.22	124.49	114.05	127.32	118.29	116.76
	(26.11)	(15.58)	(38.37)	(53.15)	(32.15)	(49.72)	(29.86)	(50.28)	(61.82)	(20.22)
	11	12	13	14	15	16	17	18	19	20
1	88.09	80.69	131.00	122.09	124.12	85.86	105.04	91.00	137.22	84.35
2	84.51	82.82	130.33	102.73	92.71	84.29	76.52	115.69	93.39	75.40
3	117.84	95.17	125.75	107.63	69.95	113.90	119.03	109.97	102.39	96.45
4	96.45	113.01	104.29	122.37	97.26	88.30	52.55	113.51	89.25	141.02
5	89.13	81.68	94.31	68.91	84.99	91.56	95.01	92.83	126.31	97.30
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

p-value	0.76	0.60	0.68	0.80	0.90	0.51	0.97	0.76	0.88	0.56
CI	78.59	73.55	96.30	77.63	69.14	77.74	57.50	89.97	83.58	67.58
	111.82	107.81	137.98	131.87	118.47	107.83	121.75	119.22	135.84	130.23
	(33.23)	(34.26)	(41.68)	(54.24)	(49.33)	(30.09)	(64.25)	(29.25)	(52.26)	(62.65)

Table 4.5 Sample sets of six(6) runs

	1	2	3	4	5	6	7	8	9	10
1	88.18	75.37	118.22	81.36	110.83	78.23	95.40	90.52	88.68	85.70
2	102.52	35.44	95.90	97.81	120.66	116.14	122.78	108.94	124.93	128.68
3	106.56	103.84	90.89	66.92	127.47	90.91	116.60	110.06	128.52	116.85
4	96.80	129.46	107.41	98.68	130.14	90.27	104.29	107.99	118.99	95.06
5	111.40	106.80	115.97	87.99	64.76	91.54	97.44	82.21	99.78	114.21
6	73.32	104.63	122.26	110.36	103.00	85.10	43.79	100.51	114.37	100.98
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.97	0.55	0.87	0.96	0.85	0.37	0.49	0.74	0.90	0.97
CI	81.88	58.11	95.09	74.53	84.12	78.55	67.28	88.06	96.38	90.31
	111.05	127.06	121.80	106.51	134.83	105.51	126.16	112.02	128.71	123.52
	(29.17)	(68.95)	(26.71)	(31.97)	(50.71)	(26.95)	(58.88)	(23.96)	(32.33)	(33.21)
	11	12	13	14	15	16	17	18	19	20
1	113.70	93.17	103.94	103.42	105.88	111.84	116.55	129.88	91.74	113.74
2	89.22	116.59	99.60	83.29	75.87	105.70	99.42	85.05	121.38	137.95
3	106.93	82.17	79.69	119.08	86.76	116.04	77.35	114.90	96.06	127.49
4	89.50	114.10	80.84	100.35	115.42	117.34	89.86	74.40	125.62	122.55
5	77.15	85.05	98.17	118.66	112.35	123.57	86.88	96.65	89.79	114.53
6	89.42	122.19	126.22	91.88	124.85	132.08	91.72	100.75	79.98	133.99
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.53	0.76	0.93	0.93	0.89	0.96	0.87	0.99	0.70	0.96
CI	80.22	83.88	80.12	87.77	84.03	108.12	79.65	79.25	81.42	114.57
	108.42	120.54	116.04	117.79	123.02	127.41	107.61	121.28	120.10	135.51
	(28.20)	(36.66)	(35.92)	(30.02)	(38.99)	(19.29)	(27.96)	(42.03)	(38.69)	(20.94)

In these tables, the parentheses in the confidence interval column describe the range of the interval. In Table 4.2 of three simulation runs, 13 sets of 20 have the range of confidence interval of more than 70. They are underlined and shaded. In Table 4.3 of four runs, 6 sets of 20 have the range of confidence interval of more than 70. However, in Table 4.4 of five runs and

Table 4.5 of six runs, no set of 20 is over the range of confidence interval of 70.

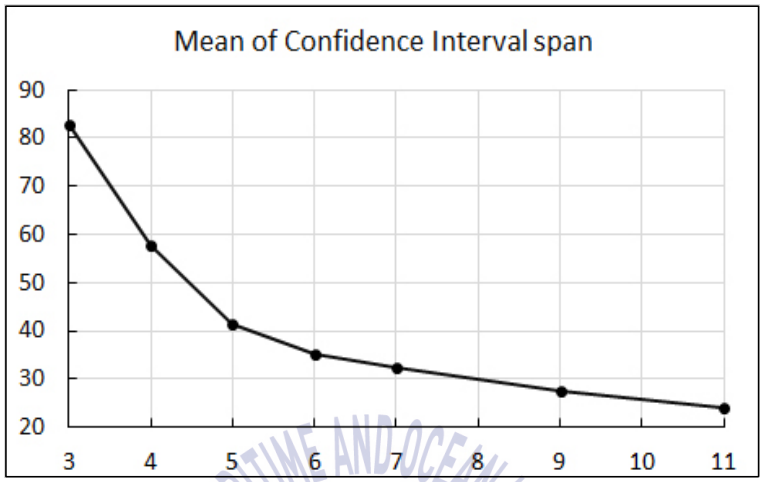


Fig. 4.1 Mean of confidence interval span of case 6

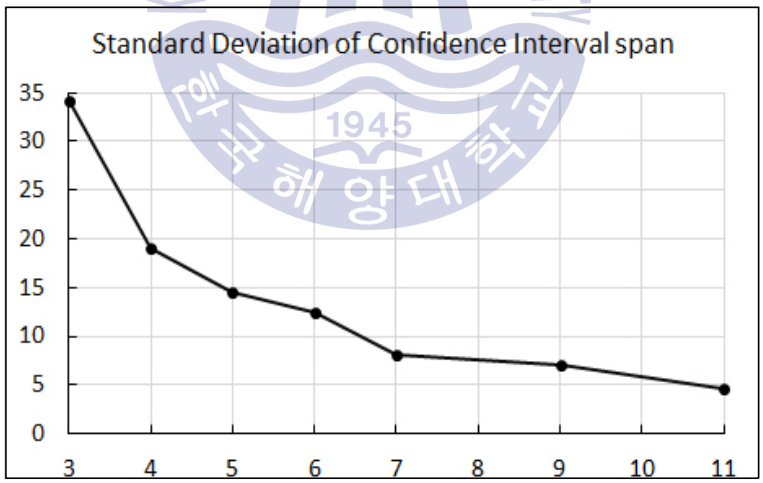


Fig. 4.2 Standard deviation of confidence interval span of case 6

As shown in Fig. 4.1, when the simulation runs are 3 and 4, the slope of the curve is very big. But after 5 the curve becomes relatively smooth. The same situation is shown in Fig. 4.2, When the simulation runs is more than 5, the curve becomes smooth. This indicates that after 5 simulation runs the result is

beginning to stabilize.

4.2.2 Box-figures and confidence interval of case 6

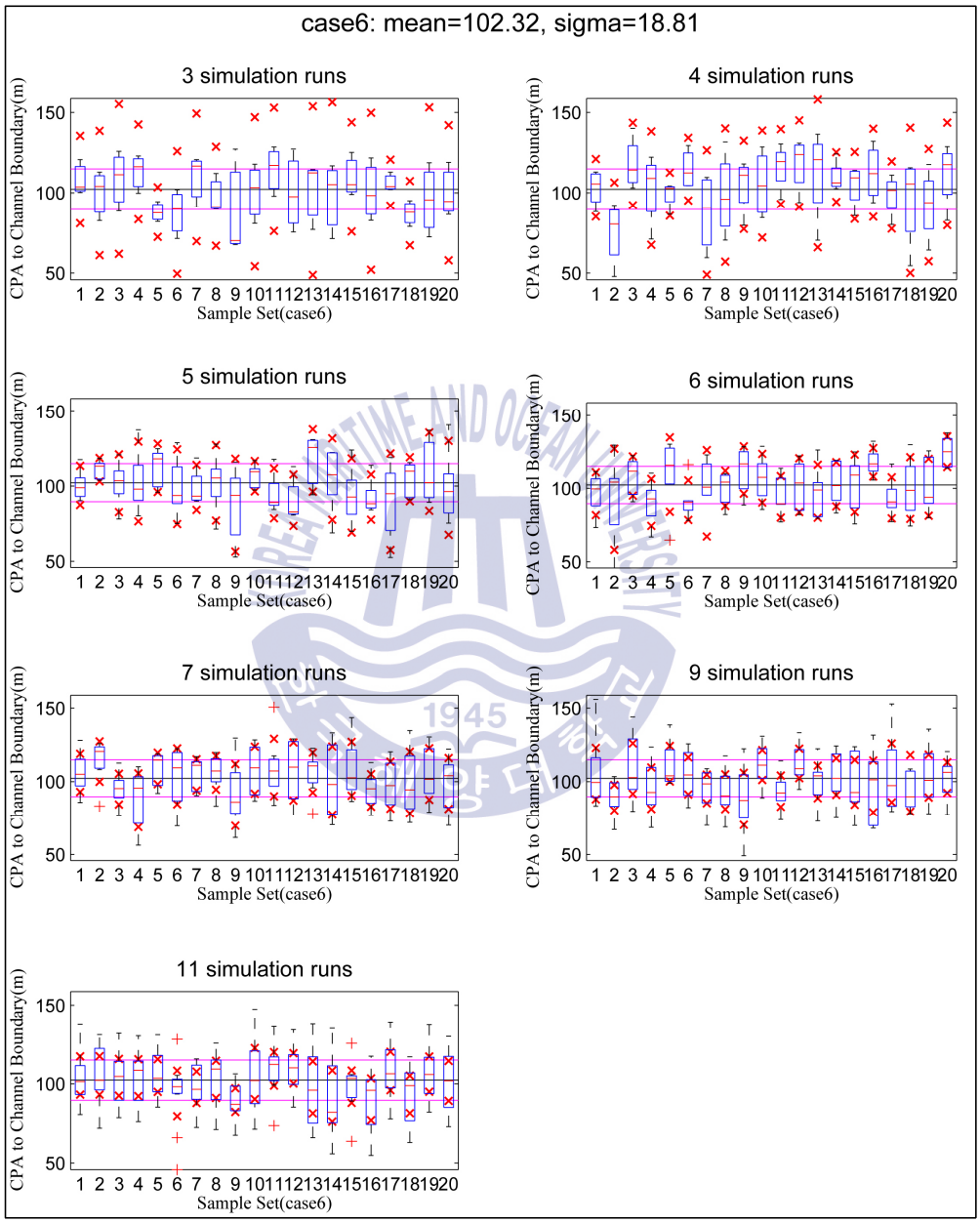


Fig. 4.3 Box-plots of case 6

As shown in Fig. 4.3, when the size of simulation runs is 3 or 4, the box interval of each box-plot fluctuates wildly, some boxes deviate from the interval [μ-0.6745σ, μ+0.6745σ] seriously, such as set 5 and set 18 in 3 simulation runs. At the same time the range of some boxes is significant, such as set 2 and set 5 in 4 simulation runs. When the simulation runs more than 5, the box of each box-plot approximates to interval [μ-0.6745σ, μ+0.6745σ] gradually.

4.2.3 Data of case 7

Case 7:

Average : μ=90.54(m)

Standard deviation : σ^2=16.39^2

Collision probability : 1.66×10^{-8}

Table 4.6 Sample sets of three(3) runs

	1	2	3	4	5	6	7	8	9	10
1	90.57	114.05	76.72	85.46	99.77	78.24	100.57	117.01	128.47	83.69
2	74.75	93.19	70.47	82.08	76.57	77.02	89.03	106.75	90.09	115.29
3	89.47	122.04	94.98	83.06	91.15	90.88	101.43	97.81	93.86	90.83
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.70	0.85	0.84	0.86	0.91	0.71	0.70	0.98	0.72	0.82
CI	62.98	72.75	49.09	79.21	60.02	62.99	79.81	83.32	51.59	55.43
	106.88	146.77	112.36	87.85	118.30	101.10	114.21	131.06	156.69	137.78
	(43.91)	(74.02)	(63.27)	(8.64)	(58.28)	(38.11)	(34.39)	(47.74)	(105.10)	(82.35)
	11	12	13	14	15	16	17	18	19	20
1	85.21	90.54	110.15	97.64	100.43	53.43	113.20	76.28	67.27	78.21
2	93.40	106.34	96.27	110.38	116.54	88.79	72.83	80.48	72.58	125.54
3	70.97	94.46	75.83	78.25	85.85	104.15	71.59	86.04	116.72	82.82
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.91	0.83	0.93	0.93	0.98	0.87	0.66	0.95	0.73	0.72
CI	55.00	76.67	51.19	55.23	62.81	17.51	27.06	68.76	18.08	30.70
	111.39	117.56	136.98	135.62	139.07	146.74	144.69	93.10	152.97	160.35
	(56.39)	(40.89)	(85.80)	(80.39)	(76.26)	(129.23)	(117.62)	(24.34)	(134.89)	(129.65)

Table 4.7 Sample sets of four(4) runs

	1	2	3	4	5	6	7	8	9	10
1	115.22	104.61	88.71	81.55	79.77	115.94	100.84	90.44	86.91	88.73
2	117.17	83.89	63.71	81.77	100.76	90.86	75.36	68.23	109.51	73.58
3	71.70	86.11	74.17	96.38	89.90	127.03	67.35	81.33	79.14	101.42
4	102.97	114.22	88.11	63.72	91.43	106.52	118.32	115.71	100.02	94.68
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.85	0.84	0.82	0.86	0.93	0.98	0.91	0.93	0.95	0.93
CI	68.34	73.88	59.54	59.58	76.78	85.71	53.20	57.02	72.39	70.71
	135.18	120.54	97.82	102.12	104.15	134.46	127.74	120.83	115.40	108.50
	(66.84)	(46.66)	(38.28)	(42.54)	(27.36)	(48.75)	(74.54)	(63.80)	(43.01)	(37.79)
	11	12	13	14	15	16	17	18	19	20
1	110.86	77.83	105.48	101.13	81.68	77.65	101.10	105.32	107.30	112.74
2	74.86	75.27	81.91	114.70	117.74	72.96	106.10	106.51	105.23	68.34
3	99.77	86.90	91.85	97.52	61.88	72.48	113.81	98.75	77.77	83.06
4	104.27	92.27	76.20	129.71	80.60	51.37	94.57	63.79	103.25	79.10
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.74	0.91	0.94	0.91	0.72	0.51	0.99	0.60	0.48	0.75
CI	72.42	70.49	68.45	87.48	48.32	49.95	90.97	61.51	76.36	55.58
	122.46	95.65	109.27	134.06	122.64	87.28	116.82	125.67	120.41	116.04
	(50.05)	(25.17)	(40.83)	(46.58)	(74.32)	(37.33)	(25.85)	(64.16)	(44.05)	(60.45)

Table 4.8 Sample sets of five(5) runs

	1	2	3	4	5	6	7	8	9	10
1	96.23	94.95	100.95	73.19	59.15	67.44	96.48	73.53	97.24	99.44
2	96.49	68.41	107.95	86.79	43.99	102.86	75.12	105.17	99.08	108.78
3	81.57	103.75	119.87	75.75	109.01	126.81	109.09	86.73	102.52	94.93
4	101.51	78.47	94.27	76.05	80.41	73.27	84.81	92.05	99.78	82.59
5	75.09	93.98	86.11	108.77	99.34	89.06	94.70	77.77	74.21	72.12
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.64	0.79	0.99	0.63	0.97	0.97	0.97	0.97	0.33	0.96
CI	76.20	70.28	85.79	65.80	44.75	62.16	76.14	71.56	80.24	73.70
	104.15	105.55	117.87	102.41	112.01	121.61	107.94	102.54	108.89	109.44
	(27.95)	(35.27)	(32.09)	(36.61)	(67.26)	(59.45)	(31.80)	(30.98)	(28.65)	(35.74)
	11	12	13	14	15	16	17	18	19	20
1	100.80	63.54	63.95	84.28	94.31	118.26	87.43	131.47	104.59	91.03
2	94.27	80.61	105.30	101.93	92.33	106.57	94.45	81.45	91.60	83.20

3	75.95	103.48	84.28	132.60	92.14	75.28	82.86	109.22	77.30	103.29
4	97.19	99.87	100.74	107.68	82.66	79.84	112.39	86.41	101.32	109.21
5	78.08	95.97	80.82	96.80	58.64	100.74	130.93	95.54	99.24	108.31
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.78	0.78	0.96	0.89	0.64	0.93	0.87	0.96	0.82	0.86
CI	75.06	68.16	66.42	82.50	65.53	73.58	76.93	75.82	81.29	84.82
	103.46	109.23	107.61	126.82	102.50	118.69	126.29	125.81	108.34	113.20
	(28.41)	(41.07)	(41.20)	(44.32)	(36.97)	(45.11)	(49.36)	(49.99)	(27.05)	(28.38)

Table 4.9 Sample sets of six(6) runs

	1	2	3	4	5	6	7	8	9	10
1	103.03	91.62	96.32	83.54	72.43	96.83	91.06	111.29	90.17	86.36
2	93.88	106.93	82.53	99.76	83.91	76.56	73.29	107.42	119.82	83.14
3	146.33	68.09	108.05	83.51	106.83	60.29	67.52	121.45	99.95	85.69
4	98.02	54.24	77.51	59.81	76.26	79.88	88.24	96.01	113.80	114.60
5	96.69	99.10	93.49	77.42	80.51	113.52	93.11	84.39	101.78	91.59
6	91.19	84.68	85.93	106.93	112.93	101.86	66.71	73.78	103.78	74.48
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.31	0.97	0.98	0.92	0.64	0.98	0.76	0.97	0.91	0.70
CI	83.12	63.38	79.10	67.63	71.09	67.77	67.23	80.37	93.83	75.04
	126.59	104.84	102.17	102.69	106.53	108.54	92.75	117.74	115.93	103.58
	(43.47)	(41.46)	(23.07)	(35.06)	(35.44)	(40.77)	(25.53)	(37.36)	(22.10)	(28.54)
	11	12	13	14	15	16	17	18	19	20
1	85.91	66.39	91.51	84.68	118.36	91.94	72.94	83.06	103.45	91.80
2	84.64	66.11	77.87	80.71	61.94	107.07	105.94	88.32	100.49	96.19
3	87.33	94.30	111.21	89.65	93.44	83.41	77.10	68.83	84.10	86.73
4	94.03	78.36	77.22	90.14	102.37	76.24	82.76	109.33	61.28	93.17
5	89.08	85.47	90.24	88.77	60.48	99.52	114.75	113.43	73.88	95.83
6	96.11	84.52	63.71	108.24	71.86	91.47	106.36	117.69	90.85	122.94
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.92	0.92	0.96	0.39	0.91	0.99	0.72	0.81	0.99	0.27
CI	84.69	67.39	68.23	80.43	59.95	80.06	74.66	76.25	68.76	84.35
	94.34	90.99	102.35	100.30	109.53	103.15	111.95	117.30	102.59	111.20
	(9.64)	(23.60)	(34.11)	(19.87)	(49.58)	(23.09)	(37.29)	(41.05)	(33.84)	(26.85)

In these tables, the parentheses in the confidence interval column describe the range of the interval. In Table 4.6 of three simulation runs, 11 sets of 20

have the range of confidence interval of more than 60. They are underlined and shaded. In Table 4.7 of four runs, 6 sets of 20 have the range of confidence interval of more than 6. However, in Table 4.8 of five runs and Table 4.9 of six runs, no set of 20 is over the range of confidence interval of 60.

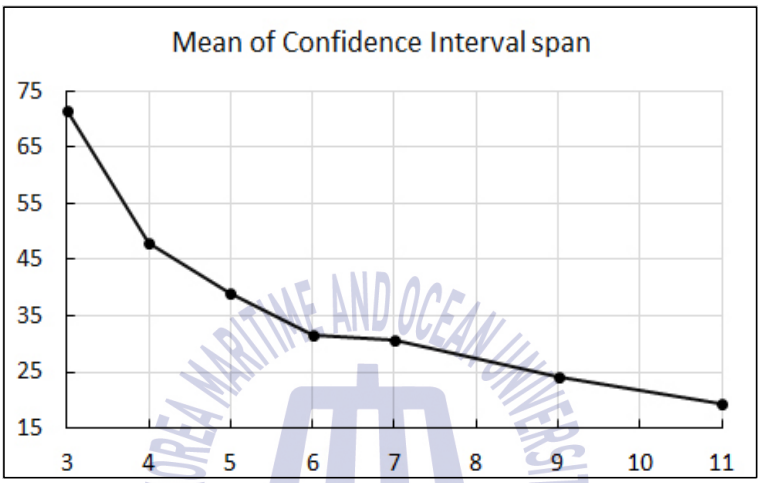


Fig. 4.7 Mean of confidence interval span of case 7

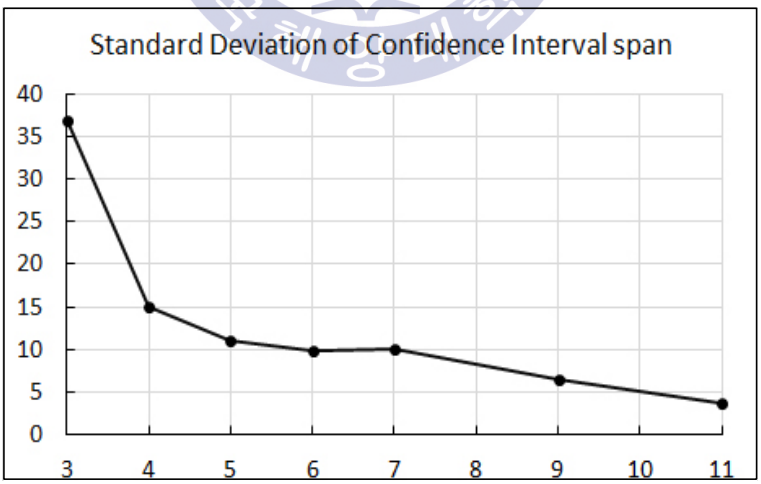


Fig. 4.8 Standard deviation of confidence interval span of case 7

As shown in Fig. 4.7, when the simulation runs are 3 and 4, the slope of the

curve is very big. But after 5 the curve becomes relatively smooth. The same situation is shown in Fig. 4.8, When the simulation runs is more than 5, the curve becomes smooth. This indicates that after 5 simulation runs the result is beginning to stabilize.

4.2.4 Box-figures and confidence interval of case 7

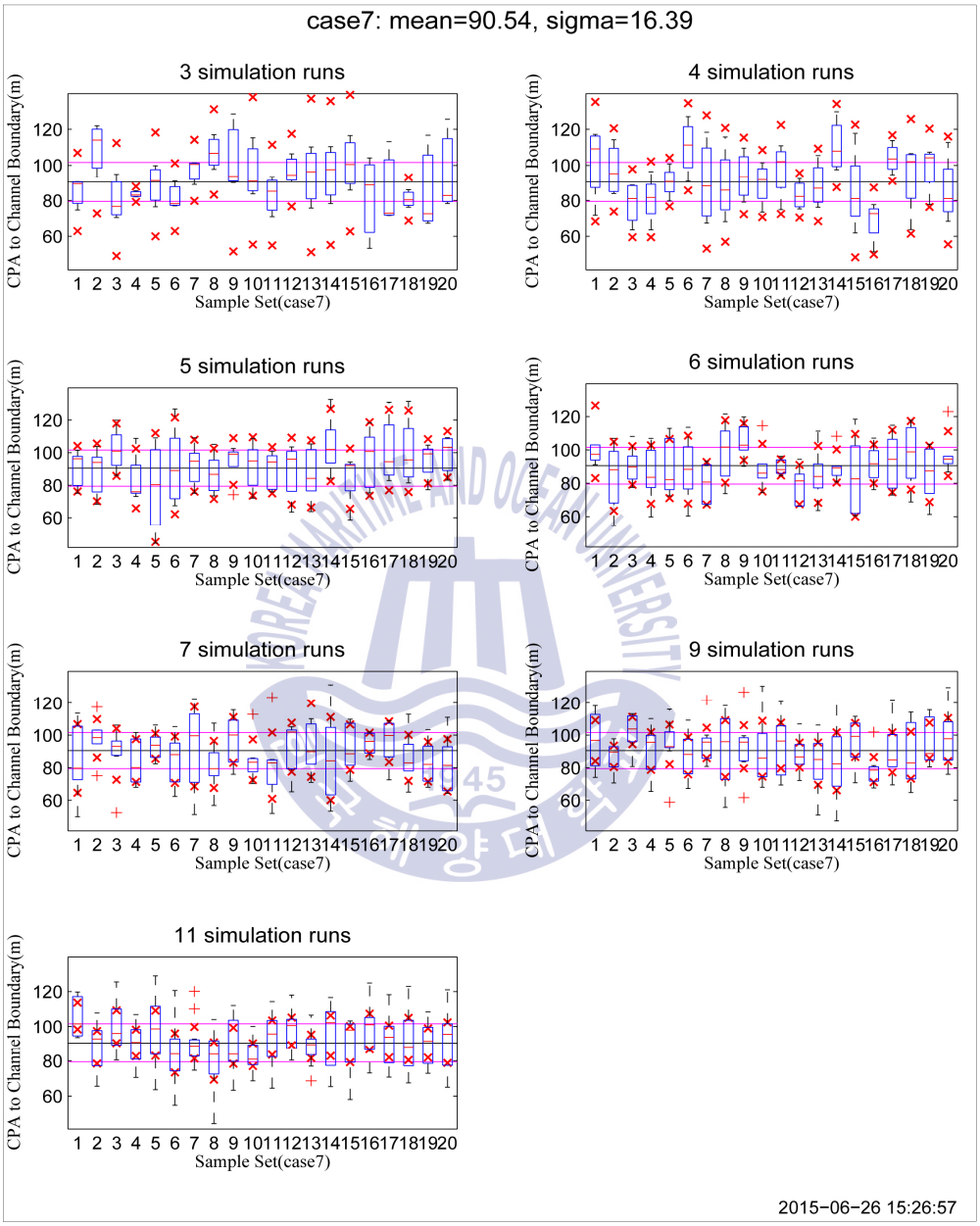


Fig. 4.9 Box-plots of case 7

As shown in Fig. 4.9, when the size of simulation runs is 3 or 4, the box interval of each box-plot fluctuates wildly, some boxes deviate from the

interval [μ-0.6745σ, μ+0.6745σ] seriously, such as set 6 and set 16 in 4 simulation runs. At the same time the range of some boxes is significant, such as set 4 and set 19 in 4 simulation runs. When the simulation runs is more than 5, the box of each box-plot approximates to interval [μ-0.6745σ, μ+0.6745σ] gradually.

4.2.5 Data of case 8

Case 8:

Average : μ=90.66(m)

Standard deviation : σ^2=16.85^2

Collision probability : 3.72×10^{-8}

Table 4.10 Sample sets of three(3) runs

	1	2	3	4	5	6	7	8	9	10
1	65.65	74.49	82.05	96.18	76.19	93.86	92.78	97.58	88.00	78.01
2	96.17	89.54	82.47	83.79	110.97	112.85	107.14	108.77	114.40	100.30
3	90.80	97.73	72.69	95.55	95.96	99.44	93.41	112.79	59.25	101.03
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.79	0.90	0.67	0.68	0.95	0.86	0.67	0.84	0.98	0.66
CI	43.74	57.96	65.34	74.50	51.04	77.80	77.62	86.81	18.69	60.61
	124.67	116.54	92.80	109.18	137.71	126.29	117.93	125.96	155.74	125.62
	(80.93)	(58.58)	(27.46)	(34.68)	(86.67)	(48.49)	(40.31)	(39.15)	(137.05)	(65.01)
	11	12	13	14	15	16	17	18	19	20
1	94.51	86.85	89.81	77.96	108.50	75.21	84.94	102.92	76.72	107.04
2	126.88	120.85	68.90	84.54	86.53	110.78	94.12	106.50	105.44	94.23
3	114.72	90.93	61.65	119.78	68.92	117.05	89.58	88.05	86.97	92.17
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.91	0.75	0.84	0.78	0.96	0.78	0.99	0.80	0.90	0.76
CI	71.42	53.42	37.13	38.24	38.72	44.96	78.15	74.86	53.55	77.80
	152.66	145.66	109.78	149.95	137.25	157.07	100.95	123.46	125.86	117.83
	(81.24)	(92.24)	(72.65)	(111.71)	(98.53)	(112.11)	(22.79)	(48.60)	(72.31)	(40.03)

Table 4.11 Sample sets of four(4) runs

	1	2	3	4	5	6	7	8	9	10

1	92.54	84.41	83.06	97.68	84.68	84.86	78.03	84.09	100.87	68.65
2	88.08	101.37	70.65	113.29	87.22	101.91	102.85	91.73	118.57	78.38
3	108.31	66.86	92.60	96.58	106.22	103.88	99.99	64.97	102.00	103.53
4	81.72	95.77	97.75	85.13	88.95	62.23	94.23	77.09	95.91	108.51
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.90	0.93	0.94	0.87	0.56	0.88	0.87	0.97	0.63	0.88
CI	74.62	62.87	67.05	79.77	76.18	57.48	76.13	61.38	88.67	59.08
	110.71	111.33	104.98	116.58	107.35	118.95	111.42	97.56	120.01	120.46
	(36.09)	(48.46)	(37.93)	(36.81)	(31.17)	(61.47)	(35.30)	(36.18)	(31.34)	(61.38)
	11	12	13	14	15	16	17	18	19	20
1	93.55	78.96	68.95	80.46	99.97	134.68	95.85	114.20	64.93	106.32
2	104.44	92.14	72.51	115.09	69.50	86.35	85.94	79.35	96.29	66.61
3	56.63	106.63	88.53	114.26	75.42	82.09	77.29	82.62	103.98	110.27
4	86.52	85.38	85.21	58.61	95.07	78.93	90.65	67.60	76.43	113.15
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.85	0.94	0.91	0.80	0.90	0.48	0.96	0.72	0.92	0.50
CI	52.71	71.91	63.64	48.27	61.43	53.68	74.89	54.26	56.89	64.35
	117.87	109.65	93.96	135.94	108.55	137.34	99.98	117.62	113.92	133.82
	(65.16)	(37.74)	(30.32)	(87.67)	(47.12)	(83.66)	(25.09)	(63.37)	(57.02)	(69.48)

Table 4.12 Sample sets of five(5) runs

	1	2	3	4	5	6	7	8	9	10
1	86.51	76.51	81.34	97.26	77.69	76.51	79.07	79.69	100.17	96.35
2	75.56	109.39	95.45	75.38	103.19	82.52	97.22	109.14	81.82	104.55
3	99.38	77.75	132.93	89.04	64.39	94.44	103.62	58.78	68.04	100.06
4	85.74	95.80	92.24	96.65	70.48	98.13	89.73	100.99	72.97	72.04
5	97.74	120.74	98.54	75.31	109.75	112.69	101.45	99.13	69.78	99.61
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.93	0.91	0.54	0.84	0.87	0.97	0.93	0.74	0.80	0.45
CI	76.86	71.96	75.93	73.22	60.02	75.32	81.81	64.33	62.17	78.50
	101.11	120.12	124.27	100.24	110.18	110.39	106.63	114.77	94.95	110.55
	(24.26)	(48.16)	(48.34)	(27.02)	(50.17)	(35.07)	(24.81)	(50.44)	(32.77)	(32.05)
	11	12	13	14	15	16	17	18	19	20
1	96.33	100.87	110.65	75.53	101.74	124.49	74.37	118.98	80.57	83.10
2	82.94	85.10	112.02	70.32	115.92	99.90	107.14	77.09	100.12	102.51
3	93.72	96.80	67.28	53.13	93.51	65.76	83.74	89.01	88.49	107.81
4	73.77	95.44	88.06	93.79	125.82	87.64	78.58	77.55	89.73	81.41

5	95.61	89.47	99.12	123.69	90.33	103.20	96.73	87.74	75.03	86.94
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.65	0.92	0.96	0.94	0.96	0.97	0.91	0.57	0.97	0.76
CI	76.26	85.79	72.47	49.97	86.74	69.40	71.28	68.86	74.91	77.45
	100.69	101.29	118.38	116.61	124.18	123.00	104.95	111.29	98.67	107.26
	(24.43)	(15.50)	(45.91)	(66.64)	(37.45)	(53.59)	(33.67)	(42.43)	(23.76)	(29.82)

Table 4.13 Sample sets of six(6) runs

	1	2	3	4	5	6	7	8	9	10
1	127.18	96.42	70.49	68.19	98.02	95.88	58.66	112.30	116.90	102.63
2	103.29	97.71	75.23	106.94	65.55	84.29	89.87	95.77	107.17	103.58
3	54.22	88.32	85.04	111.48	83.37	79.82	65.17	99.48	80.30	110.51
4	96.62	111.79	107.43	100.34	95.13	39.82	90.92	60.05	106.39	115.34
5	85.87	79.59	96.53	95.68	76.58	105.22	100.23	86.73	82.07	93.94
6	71.52	104.70	85.61	78.62	109.37	115.87	99.72	67.01	114.61	107.47
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.99	0.98	0.93	0.89	0.98	0.85	0.58	0.98	0.59	0.97
CI	63.06	84.41	72.45	75.87	71.32	58.94	65.38	65.91	84.37	97.85
	116.51	108.44	100.99	111.21	104.69	114.70	102.81	107.87	118.11	113.31
	(53.44)	(24.03)	(28.54)	(35.34)	(33.37)	(55.76)	(37.43)	(41.96)	(33.74)	(15.46)
	11	12	13	14	15	16	17	18	19	20
1	94.02	95.21	93.88	79.79	93.74	91.45	84.20	90.66	63.32	71.52
2	108.91	80.23	85.51	105.91	75.86	91.08	69.48	101.05	91.72	82.76
3	112.44	85.47	82.96	113.18	95.72	106.93	76.22	60.55	110.67	96.25
4	86.93	91.04	115.51	78.13	89.80	77.45	61.36	91.23	102.70	77.17
5	70.48	102.79	64.82	114.75	59.60	113.80	100.54	92.88	95.35	97.50
6	116.44	77.03	87.04	130.47	89.62	68.03	89.19	102.54	67.45	64.31
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.85	0.99	0.92	0.91	0.46	0.98	0.99	0.35	0.84	0.94
CI	79.65	78.51	70.97	81.90	69.52	73.38	65.35	73.86	68.47	67.59
	116.76	98.75	105.60	125.51	98.59	109.54	94.98	105.78	108.60	95.58
	(37.11)	(20.24)	(34.63)	(43.61)	(29.07)	(36.16)	(29.63)	(31.92)	(40.12)	(27.99)

In these tables, the parentheses in the confidence interval column describe the range of the interval. In Table 4.10 of three simulation runs, 11 sets of 20 have the range of confidence interval of more than 60. They are underlined

and shaded. In Table 4.11 of four runs, 7 sets of 20 have the range of confidence interval of more than 60. In Table 4.12 of five runs, 1 sets of 20 have the range of confidence interval of more than 60. However, in Table 4.13 of six runs, no set of 20 is over the range of confidence interval of 60.

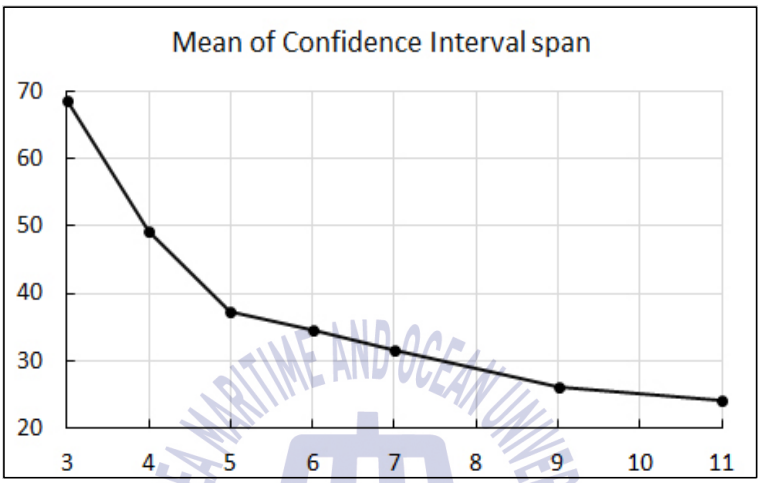


Fig. 4.7 Mean of confidence interval span of case 8

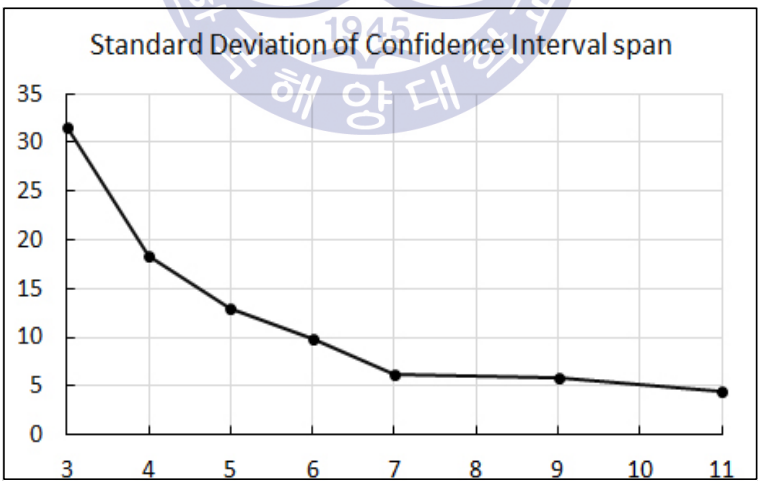


Fig. 4.8 Standard deviation of confidence interval span of case 8

As shown in Fig. 4.7, when the simulation runs are 3 and 4, the slope of the curve is very big. But after 5 the curve becomes relatively smooth. The same

situation is shown in Fig. 4.8, When the simulation runs is more than 5, the curve becomes smooth. This indicates that after 5 simulation runs the result is beginning to stabilize.

4.2.6 Box-figures and confidence interval of case 8

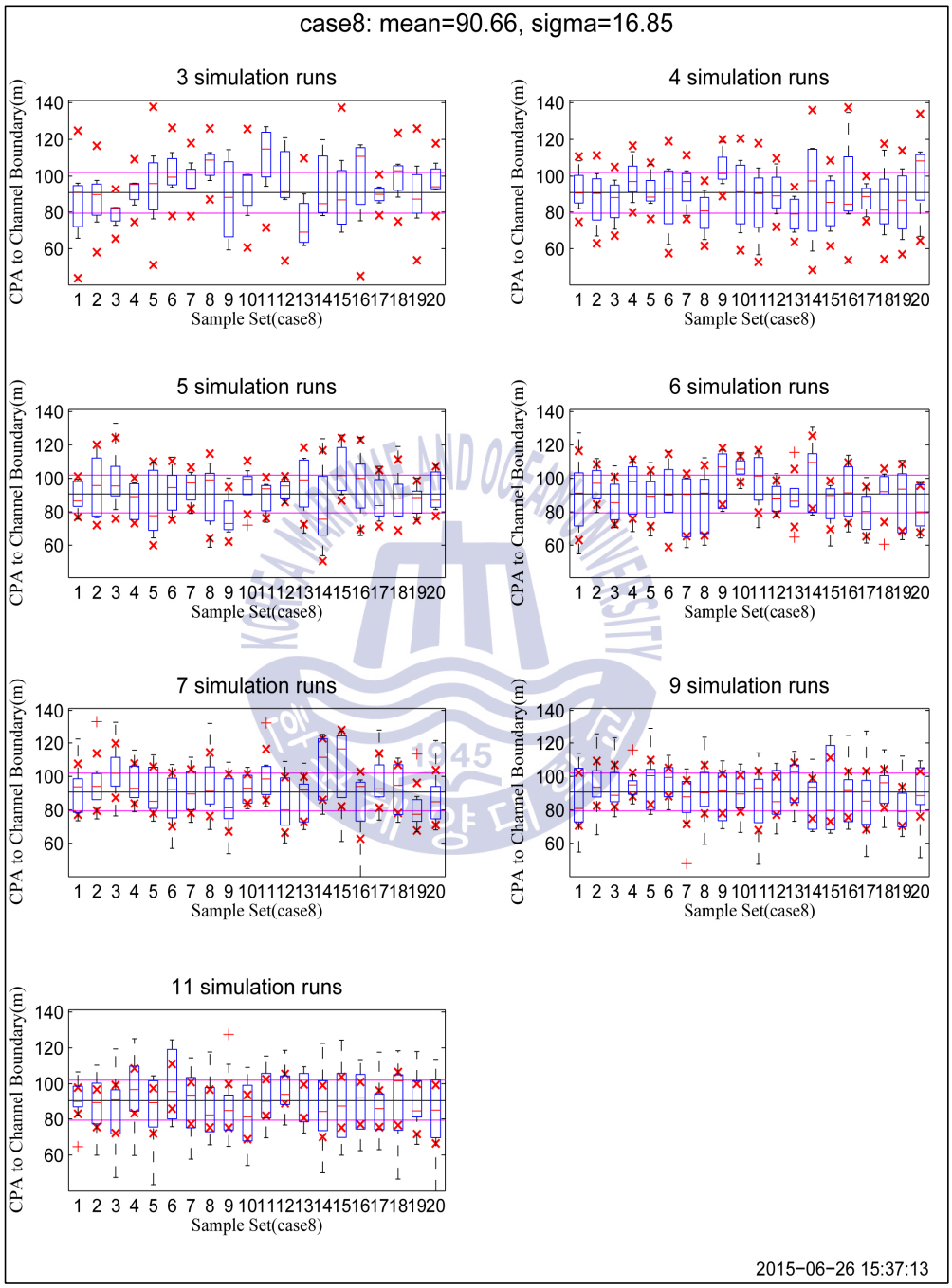


Fig. 4.9 Box-plots of case 8

As shown in Fig. 4.9, when the size of simulation runs is 3 or 4, the box interval of each box-plot fluctuates wildly, some boxes deviate from the interval [μ-0.6745σ, μ+0.6745σ] seriously, such as set 3 and set 17 in 3 simulation runs. At the same time the range of some boxes is significant, such as set 9 and set 14 in 4 simulation runs. When the simulation runs more than 5, the box of each box-plot approximates to interval [μ-0.6745σ, μ+0.6745σ] gradually.

4.2.7 Data of case 9

Case 9:

Average : μ=104.36(m)

Standard deviation : σ^2=17.89^2

Collision probability : 2.72×10^{-9}

Table 4.14 Sample sets of three(3) runs

	1	2	3	4	5	6	7	8	9	10
1	112.75	61.94	102.20	117.54	105.68	97.91	98.60	74.81	102.09	97.74
2	96.48	95.85	79.87	100.95	107.55	132.79	90.03	125.22	106.08	120.41
3	86.41	112.76	121.46	105.83	118.17	83.88	92.45	105.72	91.64	103.17
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.92	0.88	0.97	0.86	0.78	0.86	0.85	0.92	0.85	0.83
CI	65.53	25.89	49.46	86.93	93.73	42.30	82.72	38.77	81.42	77.70
	131.57	154.47	152.88	129.29	127.20	167.42	104.67	165.06	118.46	136.52
	(66.04)	(128.58)	(103.42)	(42.36)	(33.47)	(125.11)	(21.95)	(126.29)	(37.04)	(58.82)
	11	12	13	14	15	16	17	18	19	20
1	113.50	94.79	87.49	123.89	125.51	100.10	92.79	132.83	103.91	117.98
2	116.08	91.03	125.39	133.46	113.64	101.04	93.45	123.81	73.24	116.37
3	122.75	111.15	85.16	81.31	106.43	120.16	159.65	121.50	100.94	133.06
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.85	0.80	0.69	0.79	0.91	0.68	0.64	0.81	0.72	0.72
CI	105.59	72.41	43.24	43.92	91.26	78.99	19.88	111.17	50.68	99.60
	129.31	125.56	155.45	181.85	139.12	135.21	210.71	140.92	134.71	145.34
	(23.72)	(53.15)	(112.21)	(137.92)	(47.86)	(56.23)	(190.83)	(29.75)	(84.04)	(45.74)

Table 4.15 Sample sets of four(4) runs

	1	2	3	4	5	6	7	8	9	10
1	126.22	113.49	101.97	95.79	86.13	97.31	134.46	126.77	81.30	76.29
2	112.48	95.93	76.07	97.25	103.91	109.32	112.32	124.54	97.81	127.99
3	94.49	96.40	65.13	101.86	65.08	109.33	89.57	106.19	113.67	96.26
4	99.30	130.38	108.75	105.03	87.65	127.02	113.90	78.32	93.82	122.26
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.92	0.83	0.91	0.91	0.88	0.78	0.91	0.89	0.93	0.89
CI	85.43	82.96	54.97	93.23	60.35	91.27	83.37	73.30	75.41	67.55
	130.82	135.14	120.98	106.73	111.03	130.22	141.76	144.62	117.89	143.86
	(45.39)	(52.18)	(66.01)	(13.50)	(50.68)	(38.96)	(58.39)	(71.32)	(42.49)	(76.31)
	11	12	13	14	15	16	17	18	19	20
1	112.18	92.09	92.16	95.62	107.96	111.32	133.55	123.21	108.81	116.35
2	81.01	91.94	128.08	76.74	95.36	94.84	97.05	82.75	131.61	93.30
3	105.35	110.09	98.21	95.80	122.44	121.62	98.68	56.95	99.70	86.22
4	116.42	85.79	112.49	94.31	67.58	105.58	112.86	100.95	106.00	100.25
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.80	0.58	0.93	0.42	0.94	0.98	0.89	0.99	0.68	0.93
CI	78.56	78.28	82.25	75.86	61.27	90.55	83.63	46.30	89.38	78.51
	128.92	111.68	133.22	105.37	135.40	126.13	137.44	135.63	133.68	119.54
	(50.36)	(33.39)	(50.98)	(29.51)	(74.14)	(35.58)	(53.81)	(89.33)	(44.29)	(41.03)

Table 4.16 Sample sets of five(5) runs

	1	2	3	4	5	6	7	8	9	10
1	72.58	112.92	100.64	83.74	135.30	131.81	104.52	90.37	110.14	115.12
2	113.40	100.16	109.11	93.16	105.56	99.14	117.37	116.57	130.34	127.32
3	85.82	113.86	94.48	91.94	87.83	90.61	109.55	123.62	131.18	107.00
4	76.53	117.85	131.37	81.49	123.45	127.98	92.93	108.75	93.92	95.15
5	105.41	116.56	91.48	81.52	87.21	94.38	66.68	120.95	104.72	103.83
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.95	0.52	0.93	0.75	0.91	0.71	0.91	0.89	0.87	0.97
CI	68.49	103.51	85.55	79.25	81.32	84.51	73.71	95.46	93.79	94.56
	113.00	121.03	125.28	93.49	134.42	133.06	122.71	128.64	134.33	124.80
	(44.51)	(17.52)	(39.73)	(14.23)	(53.09)	(48.56)	(49.01)	(33.19)	(40.54)	(30.24)
	11	12	13	14	15	16	17	18	19	20
1	80.51	124.86	108.07	86.20	135.32	118.79	77.21	77.77	118.74	83.77
2	94.84	107.87	148.11	126.80	125.71	107.54	118.88	103.78	90.69	105.37

3	88.98	84.08	96.53	97.19	92.09	104.27	65.65	93.65	123.63	68.97
4	107.62	112.22	107.97	119.26	137.08	140.69	119.06	121.05	111.03	120.74
5	99.99	86.56	124.86	94.81	99.36	76.83	127.74	93.03	83.14	130.77
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.99	0.90	0.76	0.77	0.86	0.95	0.55	0.96	0.92	0.97
CI	81.54	81.48	92.20	83.37	92.00	80.79	66.74	78.05	83.46	70.19
	107.24	124.75	142.01	126.33	143.83	138.46	136.69	117.66	127.43	133.67
	(25.70)	(43.28)	(49.82)	(42.95)	(51.83)	(57.67)	(69.95)	(39.60)	(43.97)	(63.48)

Table 4.17 Sample sets of six(6) runs

	1	2	3	4	5	6	7	8	9	10
1	116.19	120.00	100.20	79.83	99.59	124.34	65.60	122.75	122.84	103.62
2	83.83	128.39	90.69	79.79	117.34	97.20	79.17	100.79	76.42	127.65
3	108.66	107.80	87.73	116.64	156.17	96.90	94.69	111.19	146.61	87.48
4	144.39	102.45	115.23	97.85	98.36	116.22	118.46	103.25	99.53	111.86
5	126.86	99.53	94.25	115.43	112.37	103.97	116.86	112.40	82.32	89.59
6	114.12	107.25	87.52	126.10	98.90	92.11	114.13	101.04	83.88	121.44
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.94	0.65	0.85	0.81	0.69	0.83	0.71	0.84	0.79	0.96
CI	94.61	99.29	84.84	81.74	90.45	91.90	74.92	99.57	73.00	89.67
	136.75	122.52	107.04	123.47	137.12	118.34	121.38	117.57	130.87	124.21
	(42.14)	(23.23)	(22.20)	(41.72)	(46.67)	(26.44)	(46.46)	(18.00)	(57.87)	(34.54)
	11	12	13	14	15	16	17	18	19	20
1	94.49	108.12	118.05	85.04	113.74	116.18	110.64	130.15	127.67	102.07
2	90.09	128.57	98.03	112.81	93.17	87.60	122.56	96.34	129.75	94.41
3	143.30	102.32	97.02	104.91	80.22	89.12	116.48	71.00	104.15	108.97
4	109.36	114.13	111.23	76.95	103.01	92.39	101.24	97.34	97.34	137.66
5	127.76	76.56	57.33	102.58	113.33	115.40	107.25	106.76	117.80	78.33
6	121.49	82.50	97.91	100.32	110.82	109.43	144.22	68.62	117.44	135.10
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.98	0.98	0.40	0.72	0.83	0.75	0.95	0.95	0.88	0.94
CI	93.03	81.48	74.48	83.03	88.33	87.60	101.11	70.86	102.27	85.02
	135.80	122.59	118.71	111.18	116.43	115.77	133.02	119.21	129.12	133.82
	(42.77)	(41.11)	(44.23)	(28.15)	(28.11)	(28.17)	(31.91)	(48.35)	(26.85)	(48.80)

In these tables, the parentheses in the confidence interval column describe the range of the interval. In Table 4.14 of three simulation runs, 8 sets of 20

have the range of confidence interval of more than 70. They are underlined and shaded. In Table 4.15 of four runs, 4 sets of 20 have the range of confidence interval of more than 70. However, in Table 4.16 of five runs and Table 4.17 of six runs, no set of 20 is over the range of confidence interval of 70.

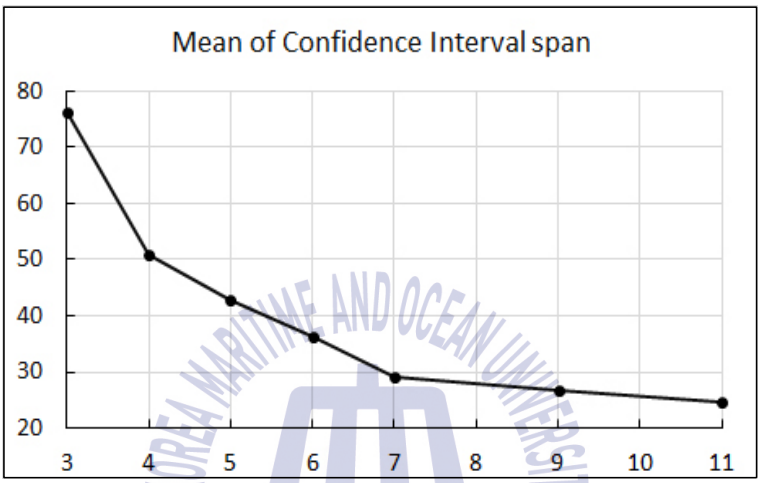


Fig. 4.10 Mean of confidence interval span of case 9

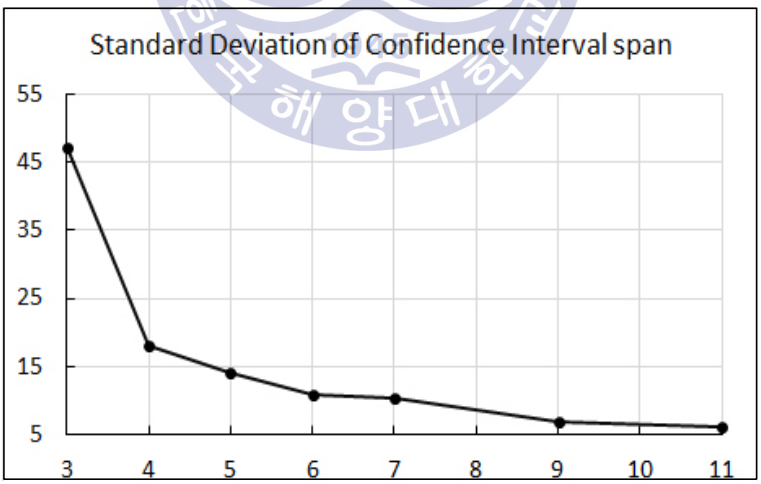


Fig. 4.11 Standard deviation of confidence interval span of case 9

As shown in Fig. 3.25, when the simulation runs are 3 and 4, the slope of

the curve is very big. But after 5 the curve becomes relatively smooth. The same situation is shown in Fig. 3.26, When the simulation runs is more than 5, the curve becomes smooth. This indicates that after 5 simulation runs the result is beginning to stabilize.

4.2.8 Box-figures and confidence interval of case 9

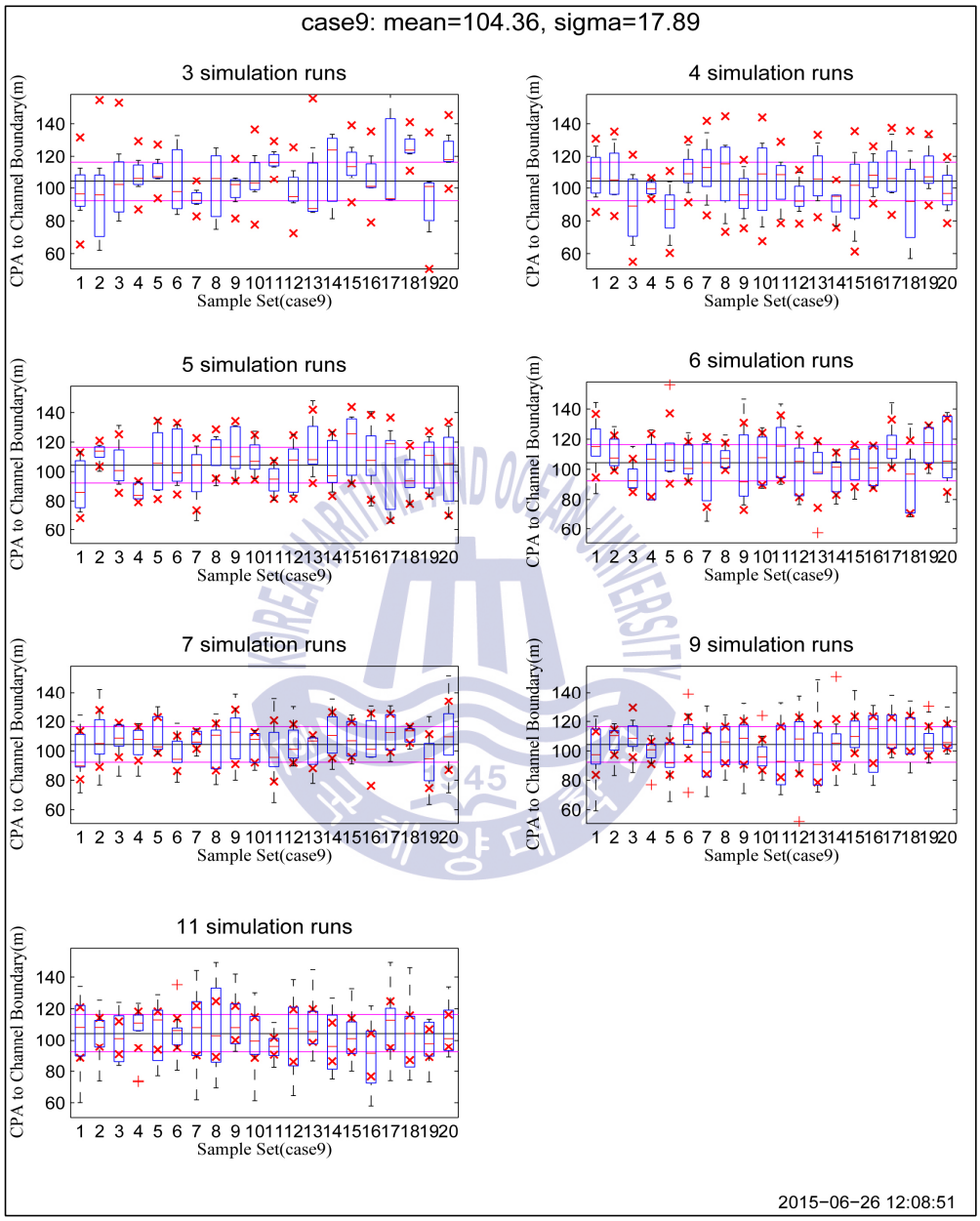


Fig. 4.12 Box-plots of case 9

As shown in Fig. 4.12, when the size of simulation runs is 3 or 4, the box interval of each box-plot fluctuates wildly, some boxes deviate from the

interval [μ-0.6745σ, μ+0.6745σ] seriously, such as set 5 and set 18 in 3 simulation runs. At the same time the range of some boxes is significant, such as set 4 and set 18 in 4 simulation runs. When the simulation runs more than 5, the box of each box-plot approximates to interval [μ-0.6745σ, μ+0.6745σ] gradually.

4.2.9 Data of case 10

Case 10:

Average : μ=107.94(m)

Standard deviation : σ^2=19.22^2

Collision probability : 9.77×10^{-9}

Table 4.18 Sample sets of three(3) runs

	1	2	3	4	5	6	7	8	9	10
1	142.79	108.07	129.68	100.86	133.07	95.99	108.69	92.96	119.32	91.09
2	124.48	96.41	74.08	136.47	96.85	71.90	93.30	117.94	102.34	91.86
3	118.85	130.53	85.80	115.46	117.11	113.86	97.37	87.94	103.40	95.01
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.82	0.89	0.81	0.94	0.96	0.95	0.84	0.79	0.69	0.80
CI	97.62	68.59	23.71	73.13	70.58	41.61	79.98	59.69	84.72	87.49
	159.80	154.75	169.34	162.06	160.78	146.22	119.60	139.54	131.98	97.81
	(62.18)	(86.15)	(145.63)	(88.92)	(90.20)	(104.61)	(39.62)	(79.85)	(47.25)	(10.31)
	11	12	13	14	15	16	17	18	19	20
1	90.26	78.73	118.43	100.36	136.38	100.66	81.58	117.78	103.64	101.85
2	94.36	74.39	89.21	124.04	112.52	90.36	141.78	109.25	102.68	112.58
3	95.60	47.80	112.19	115.23	118.30	74.80	82.99	121.19	120.05	135.17
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.82	0.77	0.81	0.91	0.83	0.93	0.66	0.85	0.68	0.88
CI	86.47	25.38	68.38	83.48	91.48	56.27	16.77	100.80	84.53	74.29
	100.35	108.57	144.84	142.94	153.32	120.95	187.47	131.35	133.04	158.79
	(13.88)	(83.20)	(76.46)	(59.46)	(61.84)	(64.68)	(170.69)	(30.55)	(48.51)	(84.50)

Table 4.19 Sample sets of four(4) runs

	1	2	3	4	5	6	7	8	9	10

1	119.84	73.64	111.76	97.07	61.06	82.36	111.78	112.53	97.39	114.22
2	96.51	114.06	126.51	108.05	88.60	117.78	89.82	124.19	65.65	91.72
3	102.63	137.67	152.29	94.76	118.70	111.80	90.70	99.76	83.66	84.60
4	135.17	108.16	126.30	108.15	117.13	128.02	84.16	101.72	99.94	86.68
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.92	0.91	0.73	0.76	0.84	0.81	0.57	0.89	0.90	0.69
CI	85.72	66.31	102.38	90.71	52.93	78.80	74.82	91.63	61.63	72.65
	141.35	150.45	156.05	113.30	139.82	141.18	113.42	127.47	111.69	115.96
	(55.62)	(84.13)	(53.67)	(22.59)	(86.89)	(62.38)	(38.60)	(35.83)	(50.05)	(43.31)
	11	12	13	14	15	16	17	18	19	20
1	123.25	124.42	125.25	106.71	129.15	83.42	97.93	114.75	118.67	113.64
2	113.27	95.92	116.99	110.21	98.33	160.92	127.58	111.01	94.49	87.62
3	110.70	74.83	81.15	106.76	89.69	96.46	96.52	121.29	123.79	76.23
4	122.94	79.92	99.97	91.97	70.24	136.45	94.27	98.24	120.69	96.40
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p	0.78	0.92	0.93	0.49	0.92	0.91	0.43	0.92	0.52	0.96
CI	107.19	58.25	74.76	90.98	57.83	62.42	79.03	95.89	93.01	68.36
	127.89	129.29	136.93	116.85	135.88	176.21	129.13	126.76	135.81	118.59
	(20.69)	(71.04)	(62.17)	(25.87)	(78.05)	(113.79)	(50.10)	(30.87)	(42.79)	(50.22)

Table 4.20 Sample sets of five(5) runs

	1	2	3	4	5	6	7	8	9	10
1	110.33	105.15	122.74	114.71	109.11	103.54	90.52	115.52	100.61	115.92
2	78.40	88.16	112.42	120.85	134.17	135.39	79.17	73.13	132.09	100.65
3	117.81	106.82	102.52	108.81	90.73	118.52	67.83	117.60	124.16	128.59
4	138.93	90.99	139.28	133.36	132.16	107.84	119.57	113.23	84.19	83.74
5	98.90	127.81	66.46	92.89	73.98	112.89	71.01	111.13	97.93	118.02
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.98	0.92	0.94	0.98	0.92	0.95	0.92	0.29	0.87	0.86
CI	81.02	84.19	74.86	95.56	75.62	100.27	59.67	83.03	83.24	87.70
	136.73	123.38	142.51	132.69	140.44	131.01	111.58	129.22	132.35	131.07
	(55.72)	(39.19)	(67.65)	(37.14)	(64.82)	(30.75)	(51.91)	(46.19)	(49.11)	(43.38)
	11	12	13	14	15	16	17	18	19	20
1	121.86	105.25	119.69	122.50	96.81	79.70	130.00	104.28	107.65	158.43
2	114.58	83.60	101.59	104.37	140.62	132.00	103.08	79.66	103.05	70.60
3	112.69	88.92	111.60	102.24	108.87	89.44	92.21	127.81	109.59	88.48
4	81.86	80.15	123.47	114.29	108.36	110.12	97.07	98.73	112.19	94.79

5	139.92	89.97	95.12	104.60	100.17	109.03	110.58	156.42	118.46	113.86
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.77	0.73	0.97	0.59	0.48	0.96	0.96	0.92	0.98	0.92
CI	88.08	77.63	95.48	98.94	89.40	78.85	88.24	76.68	103.10	63.62
	140.29	101.53	125.11	120.26	132.54	129.27	124.94	150.08	117.28	146.85
	(52.21)	(23.91)	(29.64)	(21.32)	(43.14)	(50.42)	(36.70)	(73.41)	(14.17)	(83.23)

Table 4.21 Sample sets of six(6) runs

	1	2	3	4	5	6	7	8	9	10
1	100.72	84.30	92.78	147.04	134.84	102.04	130.11	124.54	112.33	120.86
2	118.75	96.50	116.92	91.62	98.20	82.97	85.60	96.52	98.63	105.92
3	81.22	111.10	90.73	98.97	120.71	119.18	137.02	78.37	81.77	110.52
4	130.14	93.23	126.58	113.28	135.26	105.86	111.39	132.20	67.35	99.20
5	113.03	123.62	78.84	114.78	106.99	128.10	130.87	115.84	74.95	113.95
6	114.28	95.73	93.86	164.23	61.27	88.44	80.51	104.90	98.92	123.59
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.79	0.62	0.56	0.72	0.97	0.99	0.72	0.99	0.90	0.99
CI	91.98	85.90	81.08	92.00	80.27	86.24	86.89	88.07	71.10	102.74
	127.40	115.59	118.82	151.30	138.82	122.62	138.28	129.38	106.88	121.94
	(35.42)	(29.69)	(37.73)	(59.30)	(58.55)	(36.38)	(51.39)	(41.31)	(35.79)	(19.21)
	11	12	13	14	15	16	17	18	19	20
1	93.62	119.44	108.83	118.68	153.08	83.22	116.07	105.18	88.15	121.19
2	83.58	121.46	101.18	134.66	127.49	78.13	87.64	91.57	70.56	105.56
3	118.39	115.07	134.69	104.75	96.61	78.96	89.76	117.63	109.38	104.25
4	95.56	106.42	130.18	102.35	84.82	116.59	96.81	126.78	129.68	130.05
5	65.38	110.31	140.77	92.46	90.61	68.73	95.68	74.77	131.46	112.53
6	112.68	145.14	126.50	141.27	109.04	117.39	124.22	131.08	100.38	126.42
h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p-value	0.99	0.64	0.81	0.89	0.93	0.55	0.58	0.98	0.96	0.97
CI	74.58	105.28	107.50	95.45	83.10	68.41	86.03	85.04	80.01	105.27
	115.16	134.00	139.88	135.94	137.45	112.60	117.36	130.64	129.86	128.06
	(40.58)	(28.72)	(32.38)	(40.49)	(54.34)	(44.19)	(31.33)	(45.60)	(49.84)	(22.79)

In these tables, the parentheses in the confidence interval column describe the range of the interval. In Table 4.18 of three simulation runs, 10 sets of 20 have the range of confidence interval of more than 75. They are underlined

and shaded. In Table 4.19 of four runs, 4 sets of 20 have the range of confidence interval of more than 75. In Table 4.20 of five runs, 1 sets of 20 have the range of confidence interval of more than 75. However, in Table 4.21 of six runs, no set of 20 is over the range of confidence interval of 75.

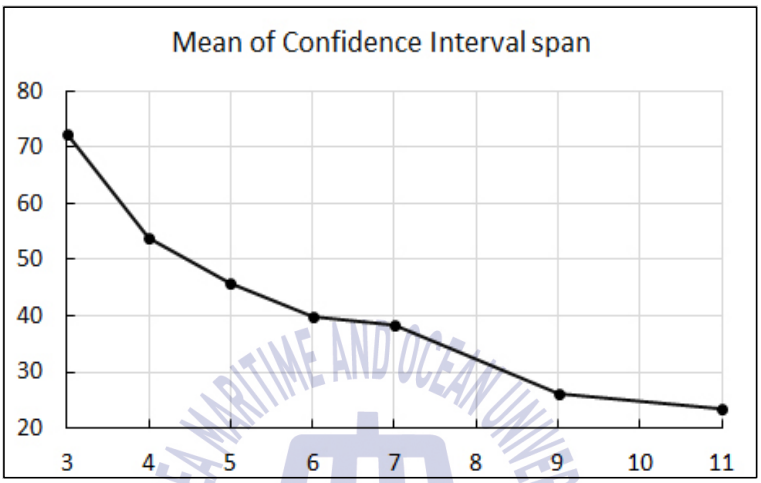


Fig. 4.13 Mean of confidence interval span of case 10

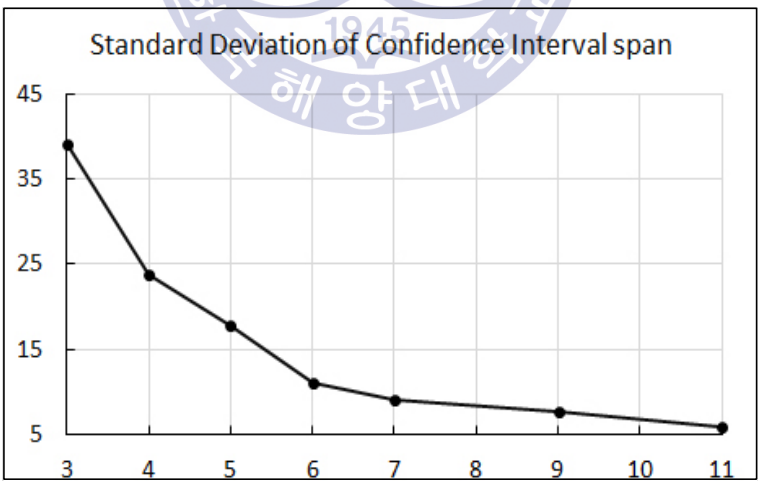


Fig. 4.14 Standard deviation of confidence interval span of case 10

As shown in Fig. 4.13, when the simulation runs are 3 and 4, the slope of the curve is very big. But after 5 the curve becomes relatively smooth. The

same situation is shown in Fig. 4.14, When the simulation runs is more than 5, the curve becomes smooth. This indicates that after 5 simulation runs the result is beginning to stabilize.

4.2.10 Box-figures and confidence interval of case 10

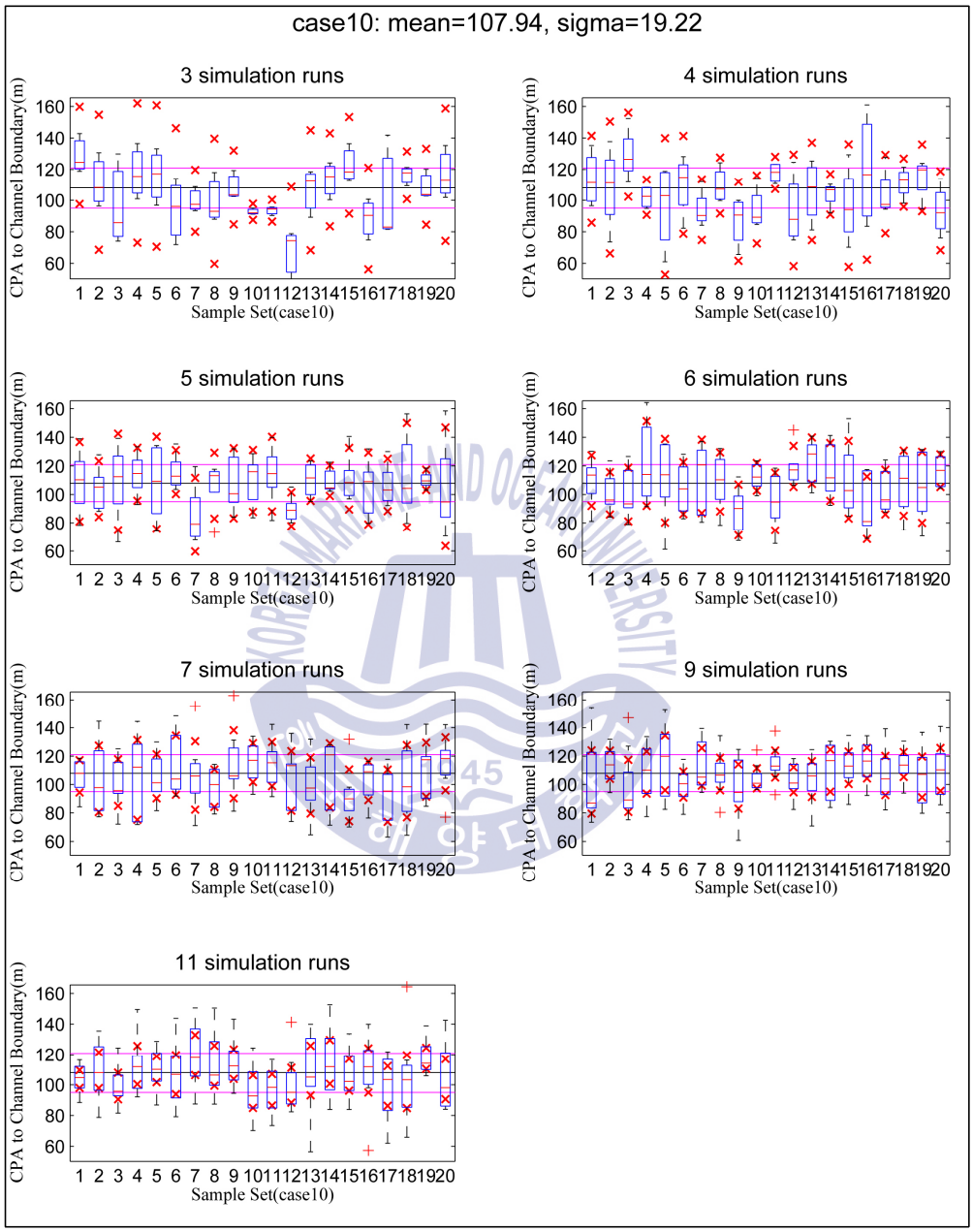


Fig. 4.15 Box-plots of case 10

As shown in Fig. 4.15, when the size of simulation runs is 3 or 4, the box interval of each box-plot fluctuates wildly, some boxes deviate from the interval [μ -0.6745 σ , μ +0.6745 σ] seriously, such as set 10, 11 and set 12 in 3 simulation runs. At the same time the range of some boxes is significant, such as set 14 and set 16 in 4 simulation runs. When the simulation runs more than 5, the box of each box-plot approximates to interval [μ -0.6745 σ , μ +0.6745 σ] gradually.

5. The determination of the minimum simulation runs

5.1 Analysis of the compare result

In chapter 3 and chapter 4, this paper generates 10 cases of data with the parameters mean and standard deviation, then used t-test to test each set of each runs in each case to get the confidence interval and confidence interval span. If the confidence interval is smaller, the mean and standard deviation of sample is closer to the mean and standard deviation of the case. Hence, the smaller the confidence interval span is, the better result can be gotten.

Table 5.1 The compare result of confidence interval span of case 1 to case 5

Case	μ	σ	COMPREF	Simulation Runs			
				3	4	5	6
1	79.35	20.29	70	16	4	1	0
2	98.57	23.87	80	11	9	1	0
3	99.5	24.33	100	16	6	0	0
4	99.34	21.48	60	14	9	0	0
5	83.72	18.62	60	14	7	1	0

μ: Mean of case
σ: Standard deviation of case
COMPREF: Compare reference

Table 5.2 The compare result of confidence interval span of case 6 to case 10

Case	μ	σ	COMPREF	Simulation Runs			
				3	4	5	6
6	102.32	18.81	70	13	6	0	0
7	90.54	16.39	60	11	6	1	0
8	90.66	16.85	60	11	7	1	0
9	104.36	17.89	70	8	4	0	0
10	107.94	19.22	75	10	4	1	0

μ: Mean of case
σ: Standard deviation of case
COMPREF: Compare reference

As shown in Table 5.1, when the size of simulation runs is 3, the confidence interval span is relatively bigger than 4 and 5 simulation runs. The confidence intervals of 9 cases out of 10 cases are bigger than those of COMPREF. When the size of simulation runs is 4, there are at least 4 sets' confidence intervals bigger than those of COMPREF. When the size of simulation runs is 5, there is only 1 or 0 sets's confidence intervals bigger than those of COMPREF.

The same situation arises in Table 5.2, it indicates that when the size of simulation runs is larger than 5, the confidence interval will be constrained within relatively tight bounds regardless of the value of collision probability.

5.2 Analysis of the stacking of mean and standard deviation of confidence interval span

In each case in chapter 3 and 4, the figure of mean and standard deviation of confidence interval span is used to show the trends of mean and standard deviation of each confidence interval span as the increase of runs, the conclusion is that when the simulation runs is more than 5, the curves become smooth. This indicates that after 5 simulation runs the results are beginning to stabilize.

If 30 experiments of case 1 and case 10 went to be performed, 30 figures could be obtained. After stacking these 30 figures, the superposed curves are shown as follows:

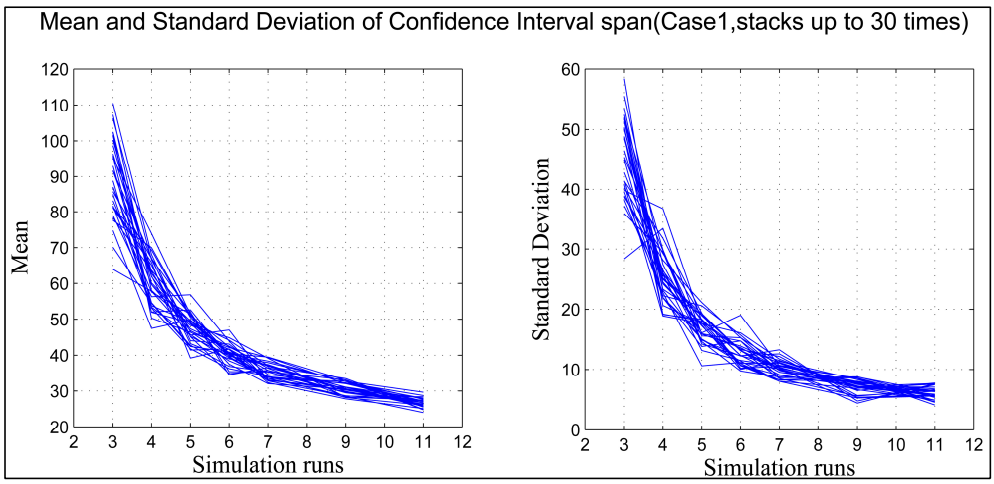


Fig. 5.1 The superposed curves of mean and standard deviation of case 1

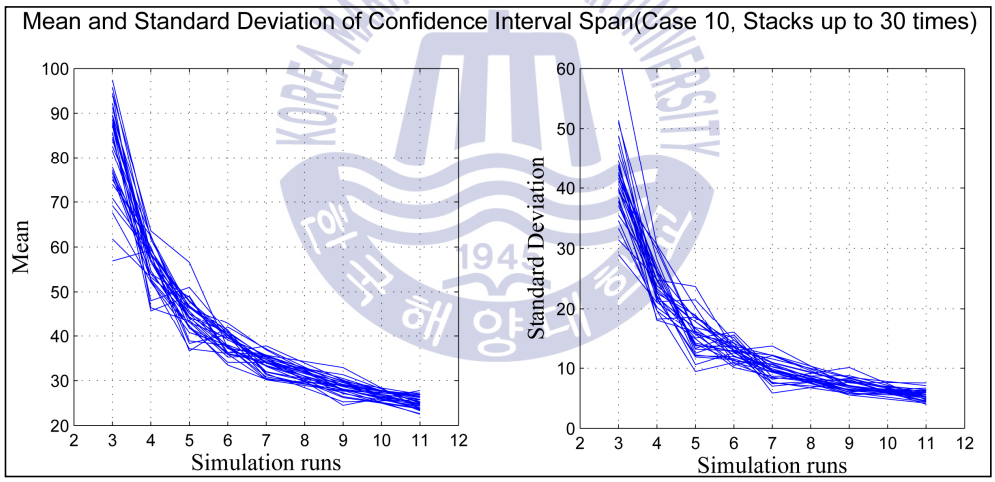


Fig. 5.2 The superposed curves of mean and standard deviation of case 10

Fig. 5.1 shows the mean and standard deviation of confidence interval accumulating 30 times with mean(79.35) and standard deviation(20.29). Fig. 5.2 shows the superposed curves when the mean is 107.94 and the standard deviation is 9.77×10^{-9}. When the size of simulation runs increases from 3 to 5, the mean and standard deviation of confidence interval span are falling rapidly,

but after 5 the curves reduce slowly. Finally, the mean curves and the standard deviation curves will tend to 0, but the size of sample will become inconceivably large.

Comparing Fig. 5.1 and Fig. 5.2, the curves groups have the same trends, it indicates that the superposed curves and the value of the collision probability are uncorrelated. Overall, when the size of sample is larger than 5, the confidence interval span is beginning to stabilize which means the simulation runs should be more than 5 times.

6. Conclusion

The Korean government introduced and enforced maritime traffic safety assessment to secure traffic safety since 2010. The vessel's proximity measure is an important factor to evaluate traffic safety. In this act it stipulates that the simulation runs should be done more than 5 times when evaluating.

In the research, mean and standard deviation of ten cases are obtained from the latest maritime traffic safety assessment which are adopted. The probability of grounding is within 10^{-4}. In order to find if it has some relationship with the collision probability, these parameters are divided into two parts: collision probability less than 10^{-4}, and collision probability less than 10^{-8}. Then each case generates twenty random sample sets. Each set constitutes the sample 3, 4, 5, 6, 7, 9 and 11, at the same time to calculate the h value and confidence interval of each sample sets. Then the box-plots which consists of twenty sample boxes is plotted, and the mean line and confidence interval are also shown on the box-plots. In the box-plots, the X-axis stands for the sample set, while the Y-axis is CPA to channel boundary.

After plotting the box-plots, the mean and standard deviation of confidence interval span are plotted in each case. These two curves show the fluctuation of confidence interval span as the runs increase.

Chapter 5 is a comprehensive analysis stage. Using the compare method, it can be found that the confidence interval spans are relatively large in 3 or 4 runs than those in 5 runs, and the value of collision probability has no relationship with the result. The superposed curves of case 1 and case 10 indicate that after 5 runs the decrease of mean and standard deviation of confidence interval span tend to stabilize, and it is also shown that the value of collision probability has no relationship with the change of curves, which also indicates that the analysis of two part data have the same result.

In summary, this study uses four measures:

1). The method of combined figures of box-plots and probability density function;

2). The method of comparing the confidence interval span and compare reference;

3). The method of mean and standard deviation of confidence interval span in each case.

4). The method of superposed mean and standard deviation of confidence interval span.

This paper uses the real parameters to generate random data and utilizes the statistics method to test the samples in each case to get the confidence interval span. In each case of this study, the 20 sample sets of data is obtained randomly by the parameter mean and standard deviation. If the actual data is used, it is difficult to ensure that the 20 sample sets of actual data have the same mean and standard deviation. Therefore it is meaningless to use the actual data to analyse. Thus this study uses the random data instead of actual data to analyse.

For the purpose of obtaining the minimum simulation run, this paper generates the random sample sets with the assumption that the population is distributed normally. And the paper carries out the KS test for goodness of fit and t-test for confidence interval. As a result the conclusions are as follows.

(1) When the size of the sample or simulation run is more than 5, the sample distribution follows the normal distribution under KS test.

(2) The confidence interval of less than 5 simulation runs is much larger than that of 5 simulation runs and more.

(3) In each case, the mean and standard deviation of the confidence interval span within less than 5 simulation runs are considerably big, but after 5 simulation runs they tend to stabilize.

(4) In the box of 25^{th} and 75^{th} percentiles of less than 5 simulation runs, the

box intervals are unstable and some of them are out of 0.5 interval of Probability Density Function.

(5) After accumulating the mean and standard deviation curves of confidence interval, when the size of simulation runs is larger than 5, a much smaller mean and standard deviation of confidence interval than those in 3 can be obtained.

(6) After comparing two parts of data, the value of collision probability has no relationship with all the methods in this study. It indicates that the simulation runs should be done more than 5 times, on condition that the collision probability is less than 10^{-4}. If the collision probability was relatively small, the same result would be obtained.

In view of the above, it is proposed that the minimum simulation runs should be more than 5 times. In future the actual data will be used to analyse and other tests other than KS test will be applied to goodness of fit for the sample distribution.

References

[1] Jeong, T.G. (2014), A Study on Determination of Minimum Sample Size for Vessel Proximity Measure in Ship-handling simulation, Spring Conference of Korea Institute of Navigation and Port Research, pp. 41-42.

[2] Jeong, T.G. & Pan, B.F. (2014), A Study on Minimum Number of Ship-handling Simulation Required for Evaluating Vessel's Proximity Measure, Journal of Korean navigation and prot research, v.38, no.6, 689-694.

[3] Kim,Y.R., J.S. Lee & S.Y. Hwang (1990), Intelligible Statistics by using Excel, p.160

[4] MOF(2013a), Regulation 11.1 of Maritime Safety Act

[5] MOF(2013b), Guidelines of Maritime Traffic Safety assessment

[6] Franz G.J. Witt, Analysis of Simulated Maneuvers

[7] An Overview of CAORF Research Data Analysis and Model Validation Performance Measures

[8] Approach Channels A Guide for Design

[9] Approach Channels Preliminary Guidelines

[10] Steven C. Chaprn & Raymond P. Cansle, numerical methods for engineers

[11] David Moore & William I. Notz, *Statistics Concepts and Controversies*

[12] David Freeman and Robert Pisani, *Statistics*

[13] John a.Rice, *Mathematical Statistics and Data Analysis*

[14] Sharon L.Lohr, *Sampling: Design and Analysis*

[15] Andreu Mas-Colell and Michael D. Whinston, *Advance Microeconomic Theory*

[16] George Casella & Roger L. Berger, *Statistical inference*

[17] Kutner M.H., *Applied Linear Statistical Models*

[18] Wendy L. Martinez & Angel R. Martinez, *Computational Statistics Handbook with MATLAB*

[19] Kermit Sigmon & Timothy A. Davis, *MATLAB Primer*

[20] Stephen J. Chapman, *Matlab Programming for Engineers Chapman*

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