

## CONSTRUCTION AND SELECTION OF SIX SIGMA BASED LINK SAMPLING PLANS

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*Paper received on 16 September 2009; accepted, 07 March 2010.*

**Abstract.** “Six Sigma is a tool used to convert management problem into a statistical problem and to find a statistical solution then convert it to a management solution”. Six Sigma [10] is a set of practices originally developed by Motorola to systematically improve processes by eliminating defects. Six Sigma asserts the following.

- A continuous effort to reduce variation in process outputs is a key to business success.
- Manufacturing and business processes can be measured, analyzed, improved and controlled.
- Succeeding at achieving sustained quality improvement requires commitment from the entire organization, particularly from top-level management.

In this paper a new procedure for the construction and selection of Link Sampling Plan (LSP) indexed through Six Sigma Quality Level-1 (SSQL-1) and Six Sigma Quality Level-2 (SSQL-2) are presented. Tables are constructed and presented for the easy selection of the plans.

**Keywords.** Six Sigma Quality Level, Poisson Distribution, Single Sampling Plan, Link Sampling Plan.

**Mathematics Subject Classification.** 62P30

# 1 Introduction

Conditional sampling plans are special purpose plans. Sampling plans are classified as cumulative and non-cumulative type. In non-cumulative sampling plans results of current sample alone are used for arriving a decision whether to accept or reject a lot. In the cumulative type sampling plans, both current and past sample results are used for making a decision. Link Sampling Plan (LSP) is one among the conditional sampling plans, which is classified as cumulative type of sampling plan. The conditional sampling procedures have been developed to reduce the inspection cost of the decision process using sample results from neighboring and related lots. This is the main advantage of conditional sampling plans.

Harishchandra and Srivenkataramana [3] have developed Link Sampling Plans. In this scheme whenever a second sample is required, the sample results from neighboring lots, (past and future) is used. The operating characteristic function of link sampling plan is identical with that of double sampling plan. Hence link sampling plan can be proposed as an alternative to double sampling situation. Moreover, in link sampling plan, the average sample number is 'n' where as in double sampling plan, the average sample number is more than 'n' if the lot requires a second sample for making a unique decision.

Radhakrishnan [4] constructed Link sampling plan for a specified Maximum Allowable Average Outgoing Quality (MAAOQ) and other various entry parameters. Devaarul [1] has made contributions to mixed sampling plans with Link sampling plan as attribute plan. Sampathkumar [6] constructed mixed sampling plan having Link Sampling Plan as attribute plan indexed through Maximum Allowable Percent Defective (MAPD), MAAOQ and other indexing parameters. Sekkizhar [7] constructed Link Sampling Plan indexed through MAPD and MAAOQ by using Intervened Random effect Poisson distribution (IRPD) as the base line distribution. Radhakrishnan and Sivakumaran [5] constructed single sampling plan indexed through six sigma quality level (SSQL).

In this paper a Link Sampling Plan is constructed by assuming the probability of acceptance of the lot,  $P_a(p)$  as  $1 - 3.4 \times 10^{-6}$ , the concept of six sigma quality suggested by Motorola [9]. The proportion defective corresponding to this probability in the OC curve is termed as Six Sigma Quality Level-1 (SSQL-1). This new sampling plan is constructed with a point on the OC curve  $(p_{ss1}, 1 - \alpha_1)$ , where  $\alpha_1 = 3.4 \times 10^{-6}$  is similar to (AQL,  $1 - \alpha$ ) suggested by Dodge and Romig [2]. The proportion defective corresponding to the probability  $2\alpha_1$  in the OC curve is termed as Six Sigma Quality Level-2 (SSQL-2). Sampling plans can also be constructed with a point on the OC curve  $(p_{ss2}, \beta_1)$ , where  $\beta_1 = 2\alpha_1$  is similar to (LQL,  $\beta$ ) suggested by Dodge and Romig [2]. The tables are also provided for the easy selection of the plans using the above concepts.

In Link Sampling Plan by attributes the lot acceptance procedure is characterized by the parameters  $N$ ,  $n_1$ ,  $n_2$ ,  $c_1$ ,  $c_2$  and  $c_3$  where  $N$ , the lot size,  $n_1$  and  $n_2$  are the sample sizes, and  $c_1$ ,  $c_2$  and  $c_3$  are the acceptance numbers. The operating procedure of a Link Sampling plan is given in section 2.

## 2 Operating procedure

**Step 1** From a lot ' $i$ ', select a random sample of size ' $n_1$ ' and find the number of defectives ' $d_i$ ' in the sample

**Step 2** If the number of defectives  $d_i \leq c_1$ , accept the lot

**Step 3** If the number of defectives  $d_i > c_3$ , reject the lot.

**Step 4** If  $c_1 < d_i \leq c_3$ , combine the total number of defectives from the immediate past and future lots,  $D_i = d_{i-1} + d_i + d_{i+1}$ .

**Step 5** If  $D_i \leq c_2$ , accept the lot ' $i$ ' and reject the lot if  $D_i > c_3$ .

## 3 Conditions for Application

- The production is steady so that results of past, present and future lots are broadly indicative of a continuing process.
- Lots are submitted sequentially in the order of their production.
- Inspection is attributes, with the quality defined as the proportion defective.
- Variation in lot quality exists.
- The sample units are selected from a big lot and production is continuous.
- Human involvement should be less in the manufacturing process.
- The company adopts Six Sigma quality initiatives in its processes.

## 4 Glossary of symbols

The symbols used in this paper are as follows:

$N$ -Lot size

$n_1$ -First sample size

$n_2$ -Second sample size

$c_1$ -First acceptance number

- $c_2$ -Second acceptance number
- $c_3$ -Third acceptance number
- $d$ -Number of defective items counted in the sample
- AQL-Acceptable Quality Level
- LQL-Limiting Quality Level
- SSQL-1-Six Sigma Quality Level-1
- SSQL-2-Six Sigma Quality Level-2
- $\alpha$ -Producer's risk
- $\beta$ -Consumer's risk
- $\alpha_1$ -Modified Producer's risk
- $\beta_1-2\alpha_1$  (Modified Consumer's risk)

## 5 Operating Characteristic (OC) function

Under Poisson model, the OC function of the Link Sampling Plan is given by

$$P_a(p) = \sum_{i=0}^{C_1} p_i + p_{c_1+1} \sum_{i=0}^{C_3-C_1-1} q_i + p_{c_1+2} \sum_{i=0}^{C_3-C_1-2} q_i + \cdots + p_{c_2} \sum_{i=0}^{C_3-C_2} q_i \quad (5.1)$$

where  $P_i = \frac{e^{-np}(np)^i}{i!}$ ,  $i = 0, 1, 2, \dots, c_2$

$q_i = \frac{e^{-knp}(knp)^i}{i!}$ ,  $i = 0, 1, 2, \dots, c_3 - (c_1 + 1)$  where  $k \geq 1$ , here it is assumed that  $k = 2$ . For the construction of tables, the case  $n_2 = kn_1$  ( $k = 2$ ) is considered.

## 6 Construction of Link Sampling Plans for a specified SSQL-1

By fixing the probability of acceptance  $P_a(p)$  of the lot provided in equation (5.1), as  $1 - 3.4 \times 10^{-6}$  with Poisson Distribution as the basic distribution, the values of  $n$  SSQL-1 are obtained for various combinations of  $c_1$ ,  $c_2$  and  $c_3$  using a Visual Basic program and presented in Table 1. The sample size ' $n_1$ ' is obtained using  $n_1 = n \text{ SSQL} - 1 / \text{SSQL} - 1$  and the values of  $n_2$  (where  $n_2 = 2n_1$ ),  $c_1$ ,  $c_2$  and  $c_3$  are also obtained for various combinations of SSQL-1.

The sigma levels of the process are calculated using the Process Sigma Calculator [8] by providing sample size and acceptance number.

**Example 1.** For a given SSQL-1 = 0.00002 and  $c_1 = 1$ ,  $c_2 = 2$  and  $c_3 = 3$ , the value of  $n$ SSQL-1 is selected from Table 1 as 0.0270 and the corresponding sample size ' $n_1$ ' is computed as  $n_1 = 0.0270/0.00002 = 1350$  and  $n_2 = 2(1350) = 2700$  which are associated with 4.6 and 4.7 sigma levels respectively. Hence the parameters of LSP are  $n_1 = 1350$ ,  $n_2 = 2700$ ,  $c_1 = 1$ ,  $c_2 = 2$  and  $c_3 = 3$  for a specified SSQL-1 = 0.00002.

**Practical application.** If the manufacturer of computer batteries fixes the quality as  $SSQL-1 = 0.00002$  (2 non-conforming batteries out of 1 lakh batteries), then take a sample of 1350 computer batteries from the manufactured lot of a particular week or month and count the number of non-conforming batteries ( $d_i$ ). If  $d_i \leq 1$ , accept the lot of batteries manufactured in that week or month and if  $d_i > 3$ , reject the lot of batteries manufactured in that week or month and inform the management for the quality improvement. If  $1 < d_i \leq 3$ , take a second sample of 2700 batteries by selecting the first '1350' items from the preceding lot and the next '1350' items from the succeeding lot and count the number of non-conforming batteries ( $D_i$ ) in the combined sample. If  $D_i \leq 2$  accept the lot of batteries manufactured in the week or month, and if  $D_i > 3$ , reject the lot of batteries manufactured in the week or month and inform the management for the quality improvement.

**Example 2.** For a given  $SSQL-1 = 0.0001$  and  $c_1 = 3$ ,  $c_2 = 4$  and  $c_3 = 5$ , the value of  $nSSQL-1$  is selected from Table 1 as 0.1820 and the corresponding sample size ' $n_1$ ' is computed as  $n_1 = 0.1820/0.0001 = 1820$  and  $n_2 = 2(1820) = 3640$  which are associated with 4.4 and 4.6 sigma levels respectively. Hence the parameters of LSP are  $n_1 = 1820$ ,  $n_2 = 3640$ ,  $c_1 = 3$ ,  $c_2 = 4$  and  $c_3 = 5$  for a specified  $SSQL-1 = 0.0001$ .

**Practical application.** If the manufacturer of garments fixes the quality as  $SSQL-1 = 0.0001$  (1 non-conforming item out of 10 thousand items), then take a sample of 1820 items from the manufactured lot of a particular day or week and count the number of nonconforming items ( $d_i$ ). If  $d_i \leq 3$ , accept the lot of items manufactured in that day or week and if  $d_i > 5$ , reject the lot of items manufactured in that day or week and inform the management for the quality improvement. If  $3 < d_i \leq 5$ , take a second sample of 3640 items by selecting the first '1820' items from the preceding lot and the next '1820' items from the succeeding lot and count the number of defective batteries ( $D_i$ ) in the combined sample. If  $D_i \leq 4$  accept the lot of items manufactured in the day or week and if  $D_i > 5$ , reject the lot of items manufactured in the day or week and inform the management for the quality improvement.

The OC curves of the plans provided in Example 1 and Example 2 are presented in Figure 1.

## 7 Construction of Link Sampling Plans for a specified SSQL-2

By fixing the probability of acceptance  $P_a(p)$  of the lot provided in equation (5.1) as  $\beta_1 = 2\alpha_1$  where  $\alpha_1 = 3.4 \times 10^{-6}$  with Poisson Distribution as the basic distribution, the values of  $nSSQL-2$  are obtained for various combinations of  $c_1$ ,  $c_2$  and  $c_3$  using a Visual Basic program and are presented in Table 2. The

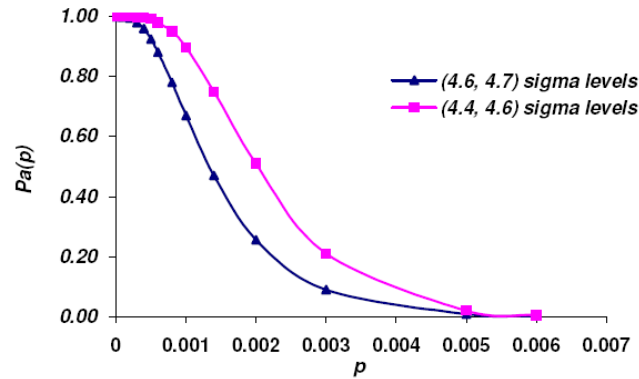


Figure 1: OC curves for the plans  $n_1 = 1350$ ,  $n_2 = 2700$ ,  $c_1 = 1$ ,  $c_2 = 2$  and  $c_3 = 3$  and  $n_1 = 1820$ ,  $n_2 = 3640$ ,  $c_1 = 3$ ,  $c_2 = 4$  and  $c_3 = 5$

sample size ' $n_1$ ' is obtained using  $n_1 = n\text{SSQL} - 2/\text{SSQL} - 2$  and the values of  $n_2$  (where  $n_2 = 2n_1$ ),  $c_1$ ,  $c_2$  and  $c_3$  are also obtained for various combinations of SSQL-2.

The sigma levels of the process are calculated using the Process Sigma Calculator [8] by providing the sample size and acceptance number.

**Example 3.** For a fixed  $\text{SSQL-2} = 0.01$ ,  $c_1 = 2$ ,  $c_2 = 4$  and  $c_3 = 5$ , the value of  $n\text{SSQL-2}$  is selected from Table 2 as 16.9880 and the corresponding sample size ' $n_1$ ' is computed as  $n_1 = 16.9880/0.01 = 1699$  and  $n_2 = 2(1699) = 3398$  which are associated with 4.6 and 4.8 sigma levels respectively. Hence the parameters of LSP are  $n_1 = 1699$ ,  $n_2 = 3398$ ,  $c_1 = 2$ ,  $c_2 = 4$  and  $c_3 = 5$  for a specified  $\text{SSQL-2} = 0.01$ .

**Explanation.** In a service oriented organisation if the customer fixes the quality as  $\text{SSQL-2} = 0.01$  (1 defective service out of 1 hundred services), then take a sample of 1699 services provided on a particular day or week and count the number of defective services ( $d_i$ ). If  $d_i \leq 2$ , accept the services provided in the day or week and if  $d_i > 5$ , reject the services provided in the same day or week and inform the management for the quality improvement. If  $2 < d_i \leq 5$ , take a second sample of 3398 services by selecting the first '1699' services from the preceding day or week and the next '1699' services from the succeeding day or week services and count the number of defective services ( $D_i$ ) in the combined sample. If  $D_i \leq 4$  accept the services provided in the day or week and if  $D_i > 5$ , reject the services provided in the combined days or weeks and inform the management for the quality improvement.

**Example 4.** For a fixed  $\text{SSQL-2} = 0.007$ ,  $c_1 = 2$ ,  $c_2 = 3$  and  $c_3 = 5$ , the value of  $n\text{SSQL-2}$  is selected from Table 2 as 16.9880 and the corresponding sample size ' $n_1$ ' is computed as  $n_1 = 16.9880/0.007 = 2427$  and  $n_2 = 2(2427) = 4854$  which are associated with 4.7 and 4.9 sigma levels respectively. Hence the

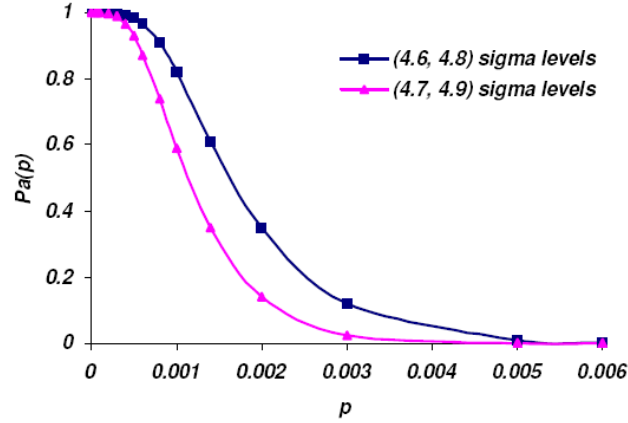


Figure 2: OC curves for the plans  $n_1 = 1699$ ,  $n_2 = 3398$ ,  $c_1 = 2$ ,  $c_2 = 4$  and  $c_3 = 5$  and  $n_1 = 2427$ ,  $n_2 = 4854$ ,  $c_1 = 2$ ,  $c_2 = 3$  and  $c_3 = 5$ .

parameters of LSP are  $n_1 = 2427$ ,  $n_2 = 4854$ ,  $c_1 = 2$ ,  $c_2 = 3$  and  $c_3 = 5$  for a specified  $SSQL-2 = 0.007$ .

**Explanation.** In a drug distributing firm if the distributor fixes the quality as  $SSQL-2 = 0.007$  (7 defective items out of 1 thousand items), then take a sample of 2427 items from the stocks of a particular day or week and count the number of defective items ( $d_i$ ). If  $d_i \leq 2$ , accept the stock of items made in the day or week and if  $d_i > 5$ , reject the stock of items made in the day or week and inform the management for the quality improvement. If  $2 < d_i \leq 5$ , take a second sample of 4854 items by selecting the first '2427' items from the preceding day or week and the next '2427' items from the succeeding day or week and count the number of defective items ( $D_i$ ) in the combined sample. If  $D_i \leq 3$  accept the items produced in the day or week and if  $D_i > 5$ , reject the items produced in the day or week and inform the management for the quality improvement.

The OC curves of the plans provided in Example 3 and 4 are presented in Figure 2.

## 8 Construction of Link Sampling Plans for a specified $SSQL-1$ and $SSQL-2$

By fixing the probability of acceptance  $P_a(p)$  of the lot provided in equation (5.1), as  $1 - 3.4 \times 10^{-6}$  with Poisson distribution as the basic distribution, the values of  $nSSQL-1$  and fixing  $\beta_1 = 2\alpha_1$  where  $\alpha_1 = 3.4 \times 10^{-6}$ , the values of  $nSSQL-2$  are obtained for various combinations of  $c_1$ ,  $c_2$  and  $c_3$  using a Visual Basic program and are presented in Table 3.

For a specified  $SSQL-1$  and  $SSQL-2$  values calculate the ratio  $R = SSQL-$

2/SSQL-1 (SSQL-2 > SSQL-1). Select the nearest  $R$  value from Table 3 and the sample size ' $n_1$ ' is obtained using  $n_1 = n\text{SSQL-1}/\text{SSQL-1}$  and the values of  $n_2$  (where  $n_2 = 2n_1$ ),  $c_1$ ,  $c_2$  and  $c_3$  are also obtained for various combinations of SSQL-1 and SSQL-2.

The sigma levels of the process are calculated using the Process Sigma Calculator [8] by providing sample size and acceptance number.

**Example 5.** For a given SSQL-1=0.00004 and SSQL-2=0.007, calculate the ratio  $R = \text{SSQL-2}/\text{SSQL-1} = 0.007/0.00004 = 175.00$ . Then the nearest  $R$  value selected from Table 3 as 175.13 and the corresponding sample size  $n_1$  is computed as  $n_1 = 0.0970/0.00004 = 2425$ ,  $n_2 = 2(2425) = 4850$  which are associated with 4.65 and 4.85 sigma levels respectively. Hence the parameters of LSP are  $n_1 = 2425$ ,  $n_2 = 4850$ ,  $c_1 = 2$ ,  $c_2 = 3$  and  $c_3 = 6$  with a specified SSQL-1 = 0.00004 and SSQL-2 = 0.007.

**Practical application.** If the manufacturer of medicines fixes the incoming quality SSQL-1 = 0.0000006 (6 non-conformities out of 1 crore medicines) and outgoing quality SSQL-2 = 0.005 (5 non-conformities out of 1 thousand), then take a sample of 2425 items from the stocks of a particular day or week and count the number of defective items ( $d_i$ ). If  $d_i \leq 2$ , accept the stock of items made in the day or week and if  $d_i > 6$ , reject the stock of items made in the day or week and inform the management for the quality improvement. If  $2 < d_i \leq 6$ , take a second sample of 4850 items by selecting the first '2425' items from the preceding day or week and the next '2425' items from the succeeding day or week and count the number of defective items ( $D_i$ ) in the combined sample. If  $D_i \leq 2$  accept the items produced in the day or week and if  $D_i > 6$ , reject the items produced in the day or week and inform the management for the quality improvement.

**Example 6.** For a given SSQL-1 = 0.000055 and SSQL-2 = 0.006, calculate the ratio  $R = \text{SSQL-2}/\text{SSQL-1} = 0.006/0.000055 = 109.09$ . Then the nearest  $R$  value selected from Table 3 as 110.31 and the corresponding sample size  $n_1$  is computed as  $n_1 = 0.1540/0.000055 = 2800$ .  $n_2 = 2(2800) = 5600$  which are associated with 4.7 and 4.9 sigma levels respectively. Hence the parameters of LSP are  $n_1 = 2800$ ,  $n_2 = 5600$ ,  $c_1 = 2$ ,  $c_2 = 4$  and  $c_3 = 5$  with a specified SSQL-1 = 0.000055 and SSQL-2 = 0.006.

The OC curves of the plans provided in Example 5 and 6 are presented in Figure 3.

## Conclusion

In this paper a new procedure for the construction and selection of Link Sampling Plans indexed through Six Sigma Quality Level-1 (SSQL-1) and Six Sigma Quality Level-2 (SSQL-2) and combination of (SSQL-1, SSQL-2) are presented separately.



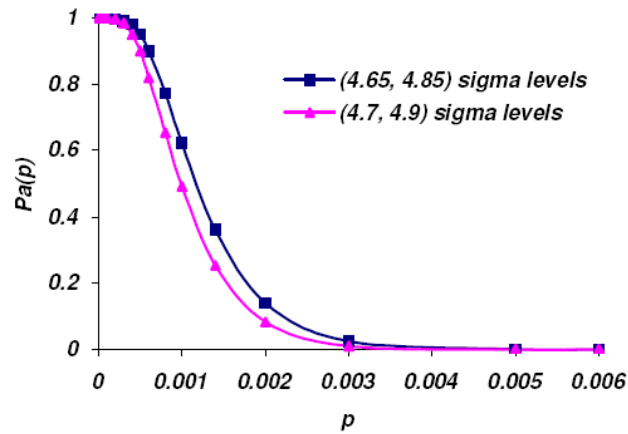


Figure 3: OC curves for the plans  $n_1 = 2425$ ,  $n_2 = 4850$ ,  $c_1 = 2$ ,  $c_2 = 3$  and  $c_3 = 6$  and  $n_1 = 2800$ ,  $n_2 = 5600$ ,  $c_1 = 2$ ,  $c_2 = 4$  and  $c_3 = 5$ .

These schemes are very effective for the manufacturers and service sectors which adopt Six Sigma quality initiatives in their systems. The tables are also provided for the easy selection of the schemes. These schemes are very useful to the companies because the producer's risk and consumer's risk are less, which results in more satisfaction for the consumers and higher profit for the manufacturers.

Table 1: Parameters of LSP for a specified SSQL-1

$c_1$	$c_2$	$c_3$	$n$ SSQL-1
0	1	1	0.0020
0	1	2	0.0030
0	2	3	0.0250
0	3	4	0.0710
1	2	3	0.0270
1	3	4	0.0760
1	3	5	0.0950
1	3	6	0.0970
1	4	4	0.0830
1	4	5	0.1406
1	4	6	0.1910
1	4	7	0.2140
2	3	4	0.0860
2	3	5	0.0960
2	3	6	0.0970
2	4	5	0.1540
2	4	6	0.1990
2	4	7	0.2160
2	4	8	0.2180
2	5	6	0.2280
2	6	8	0.4030
3	4	5	0.1820
3	5	6	0.2600
3	6	8	0.4300
4	5	6	0.3140
4	5	7	0.3590
4	5	8	0.3810
4	5	9	0.3870
5	6	7	0.4810
5	6	8	0.5370
5	8	9	0.6540
5	8	10	0.7520

Table 2: Parameters of LSP for a Specified SSQL-2

$c_1$	$c_2$	$c_3$	$n\text{SSQL-2}$
0	1	1	11.8900
0	1	2	11.8900
0	2	3	11.8900
0	3	4	11.8900
1	2	3	14.6490
1	3	4	14.6490
1	3	5	14.6490
1	3	6	14.6490
1	4	4	14.6490
1	4	5	14.6490
1	4	6	14.6490
1	4	7	14.6490
2	3	4	16.9880
2	3	5	16.9880
2	3	6	16.9880
2	4	5	16.9880
2	4	6	16.9880
2	4	7	16.9880
2	4	8	16.9880
2	5	6	16.9880
2	6	8	16.9880
3	4	5	19.1200
3	5	6	19.1200
3	6	8	19.1200
4	5	6	21.1200
4	5	7	21.1200
4	5	8	21.1200
4	5	9	21.1200
5	6	7	23.0260
5	6	8	23.0260
5	8	9	23.0260
5	8	10	23.0260

Table 3: Parameters of LSP for a Specified SSQL-1 and SSQL-2

$c_1$	$c_2$	$c_3$	$n\text{SSQL-1}$	$n\text{SSQL-2}$	$R$
0	1	1	0.0020	11.8900	5945.00
0	1	2	0.0030	11.8900	3963.33
0	2	3	0.0250	11.8900	475.60
0	3	4	0.0710	11.8900	167.46
1	2	3	0.0270	14.6490	542.56
1	3	4	0.0760	14.6490	192.75
1	3	5	0.0950	14.6490	154.20
1	3	6	0.0970	14.6490	151.02
1	4	4	0.0830	14.6490	176.49
1	4	5	0.1380	14.6490	106.15
1	4	6	0.1910	14.6490	76.70
1	4	7	0.2140	14.6490	68.45
2	3	4	0.0860	16.9880	197.53
2	3	5	0.0960	16.9880	176.96
2	3	6	0.0970	16.9880	175.13
2	4	5	0.1540	16.9880	110.31
2	4	6	0.1990	16.9880	85.37
2	4	7	0.2160	16.9880	78.65
2	4	8	0.2180	16.9880	77.93
2	5	6	0.2280	16.9880	74.51
2	6	8	0.4030	16.9880	42.15
3	4	5	0.1820	19.1200	105.05
3	5	6	0.2600	19.1200	73.54
3	6	8	0.4300	19.1200	44.47
4	5	6	0.3140	21.1200	67.26
4	5	7	0.3590	21.1200	58.83
4	5	8	0.3810	21.1200	55.43
4	5	9	0.3870	21.1200	54.57
5	6	7	0.4810	23.0260	47.87
5	6	8	0.5370	23.0260	42.88
5	8	9	0.6540	23.0260	35.21
5	8	10	0.7520	23.0260	30.62

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