Table 7.2 Fill rates with different retailer reorder points for a distribution system with echelon stock policy

R_ROP	R1	R2	R3
4	0.882	0.909	0.786
6	0.949	0.962	0.837
8	0.973	0.983	0.875
10	0.992	0.993	0.965
12	0.999	0.992	0.960
16	1.000	0.991	0.968

Table 7.3 Costs with different warehouse reorder points for a distribution system with installation stock policy vs. echelon stock policy

W1_ReOrderPoints	Cost with ISP	Cost with ESP
4	61007.54	57195.32
8	63533.72	59662.00
10	64695.10	59235.67
12	65705.00	61503.42
15	64477.48	61486.65
20	68236.58	65778.14
25	68524.75	71714.20
30	69215.68	74603.34
35	76408.40	76256.62

Table 7.4 Fill rates with different warehouse reorder points for a distribution system with installation stock policy vs. echelon stock policy

W1_ReOrderPoints	ISP-R1	ESP-R1	ISP-R2	ESP-R2	ISP-R3	ESP-R3
4	0.946	0.941	0.975	0.977	0.859	0.841
8	0.959	0.949	0.975	0.972	0.854	0.833
10	0.962	0.951	0.97	0.973	0.849	0.843
12	0.971	0.963	0.973	0.984	0.865	0.874
15	0.964	0.949	0.971	0.965	0.856	0.871
20	0.973	0.973	0.985	0.977	0.865	0.863
25	0.978	0.984	0.981	0.984	0.875	0.868
30	0.973	0.981	0.984	0.976	0.889	0.877
35	0.973	0.974	0.977	0.978	0.892	0.882

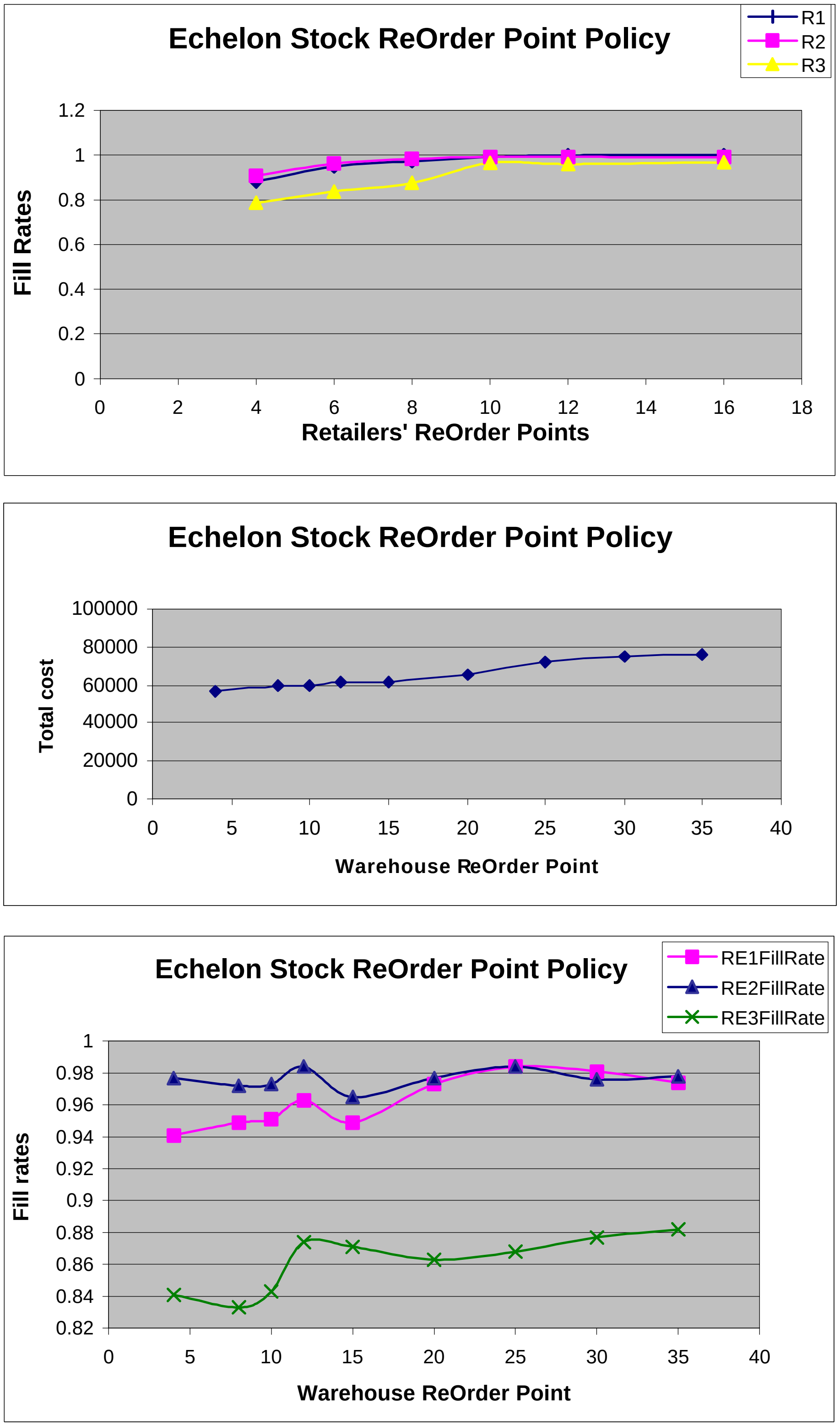


Figure 7.6 Costs and fill rates for a multi-echelon distribution system with echelon stock reorder point policy

From Figure 7.6, we see that the optimal reorder point value for warehouse is around 12 and the optimal reorder point value for retailers is around 10.

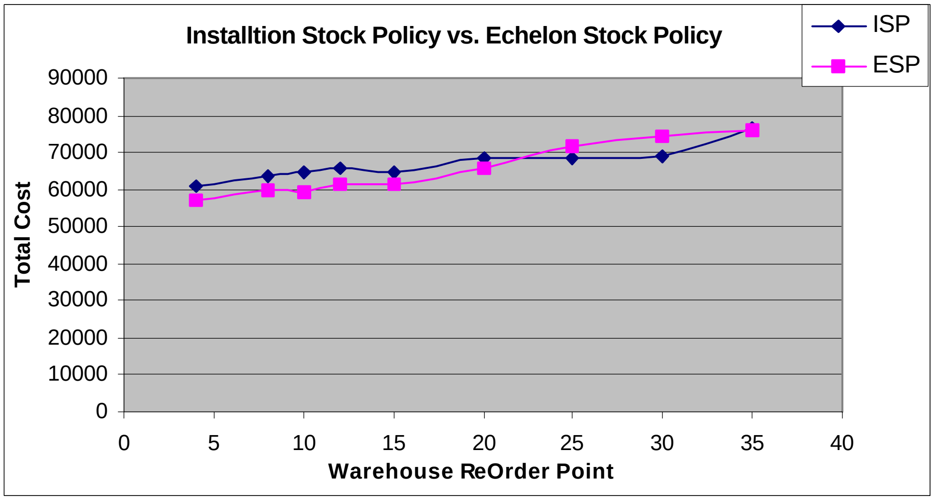


Figure 7.7 Costs with different warehouse reorder points for a distribution system with installation stock policy vs. echelon stock policy

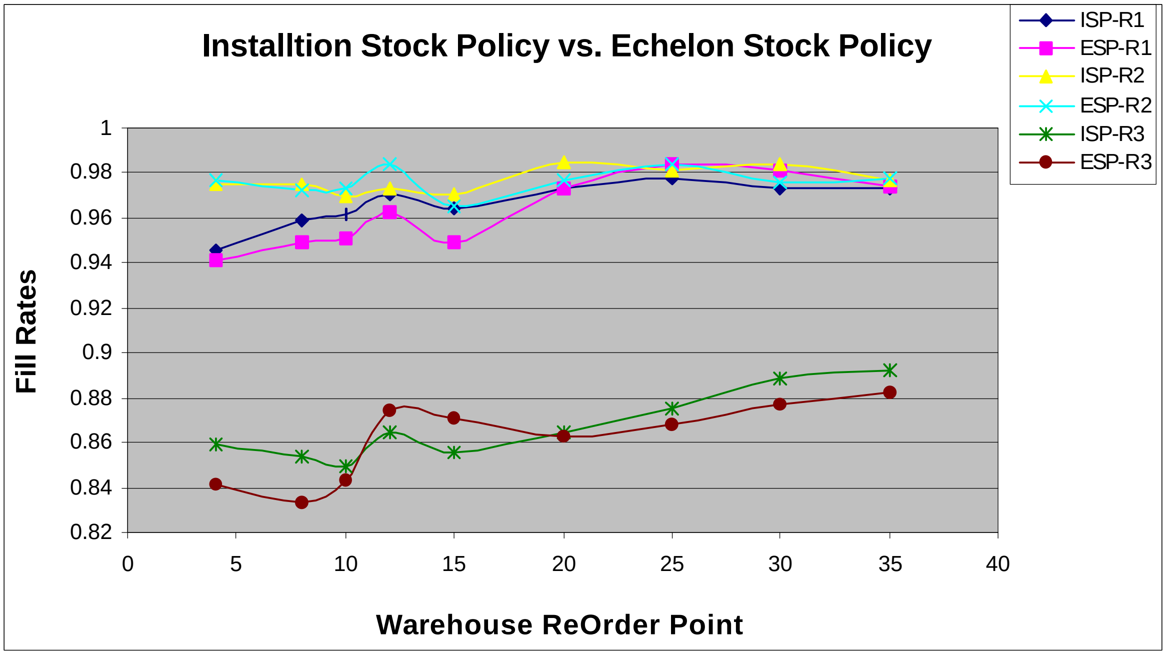


Figure 7.8 Fill rates with different warehouse reorder points for a distribution system with installation stock policy vs. echelon stock policy

By comparing the cost and fill-rate performance between installation stock policy and echelon stock policy, we have Figures 7.7 and 7.8. Figure 7.7 shows that the echelon stock policy is better (less cost) than installation stock policy when the warehouse reorder point is below 22 units. From Figure 7.8, it can be seen that the fill-rate performance curves of echelon stock policy and installation stock policy are overlapping. This indicates that either echelon stock policy or installation stock policy may be advantageous.

7.7.2 Output Analysis of A Multi-Echelon Distribution System with Lateral Transshipment

In multi-echelon research, the most common assumption is that shipments among retailers are not allowed. One reason is that it will be very difficult, if not impossible, to consider this situation. However, through simulation, the impact of lateral transshipments can be investigated. The following issues will occur in the simulation study: (1) How to evaluate the benefits of adding this flexibility? (2) In emergencies, will the service be better? and (3) How about the cost?

Some factors to be considered in the study include: (1) replenishment lead time from warehouse, (2) demand process, and (3) number of retailers in pooling group.

Generally, there are two different transshipment policies: (1) random policy and (2) risk balancing policy. The idea behind random policy is as follows: when retailer k faces a shortage and retailers i, j have available on-hand inventory, the source retailer is chosen randomly and transships as much as needed to completely eliminate the shortage. If its inventory is not sufficient, then the other retailer also sends the quantity required to eliminate the remaining shortage. The rationale behind the risk balancing policy is that the determination of transshipment quantities should also take into account the risk of stock-out in at least the following period. Since the risk should be balanced between the two senders or the two receivers, the transshipped quantities must be those that equalize the probability of a stock-out in the following period.

The previous research shows that the random policy is simple to implement, but the performance is not good. On the other hand, the system performance by employing risk-balancing policy is good. However, it is hard to implement in practice. In this section, a new transshipment policy called “alternate policy” is presented. The principle of alternate policy is as follows: when retailer k faces a shortage and retailers i, j have available on-hand inventory, both retailers i and j, alternately, transship as much as needed to eliminate the shortage. For this policy, the inventory levels of senders should not fall below their safety stocks.

In the following simulation study (three retailers), two cases are identified:

Case I: two senders and one receiver, and

Case II: one sender and two receivers.

The simulation models for a multi-echelon distribution system with different transshipment policies are shown in the following Figures.

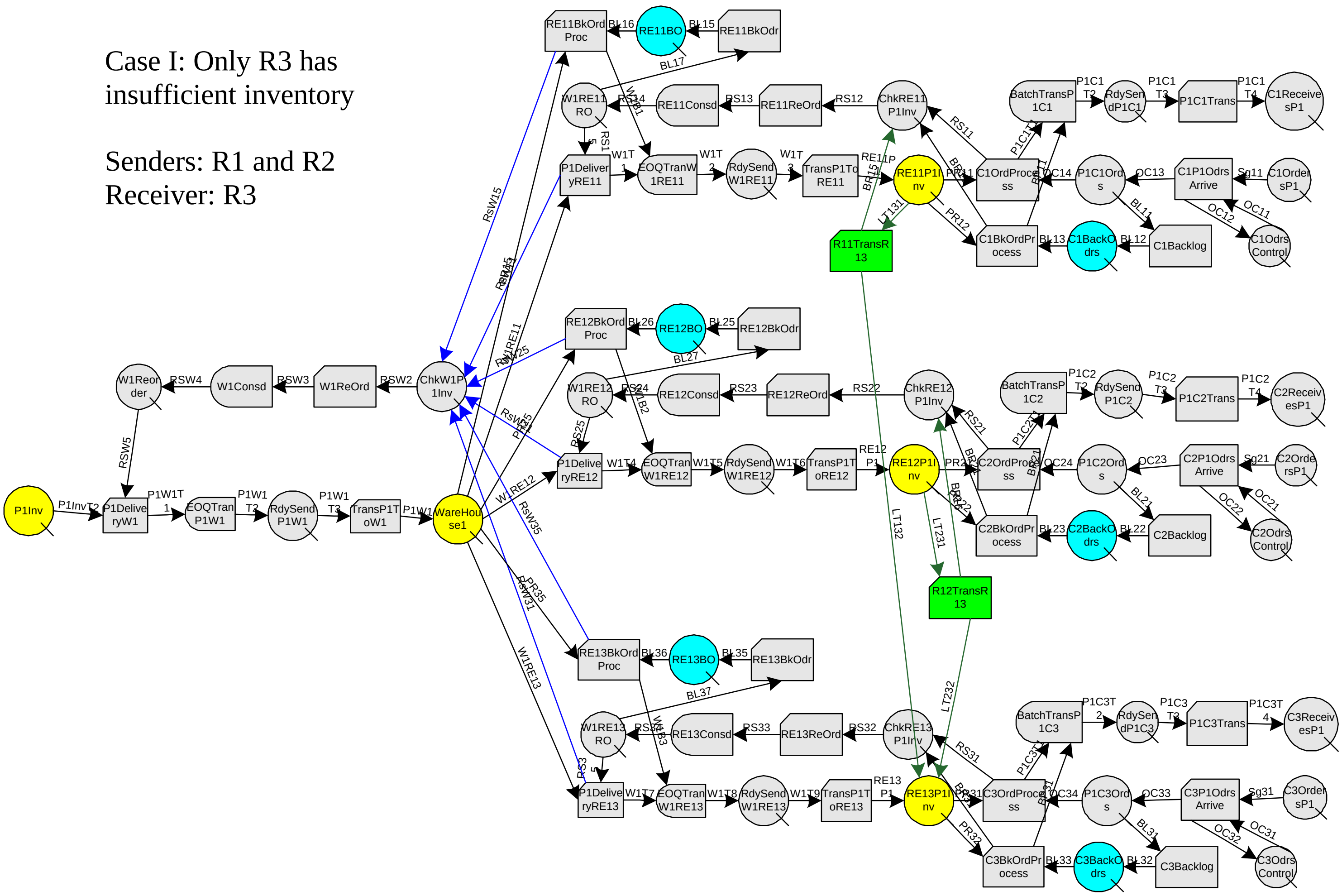


Figure 7.9 Simulation model for a multi-echelon distribution system with installation stock reorder point policy and random transshipment policy (Case I)

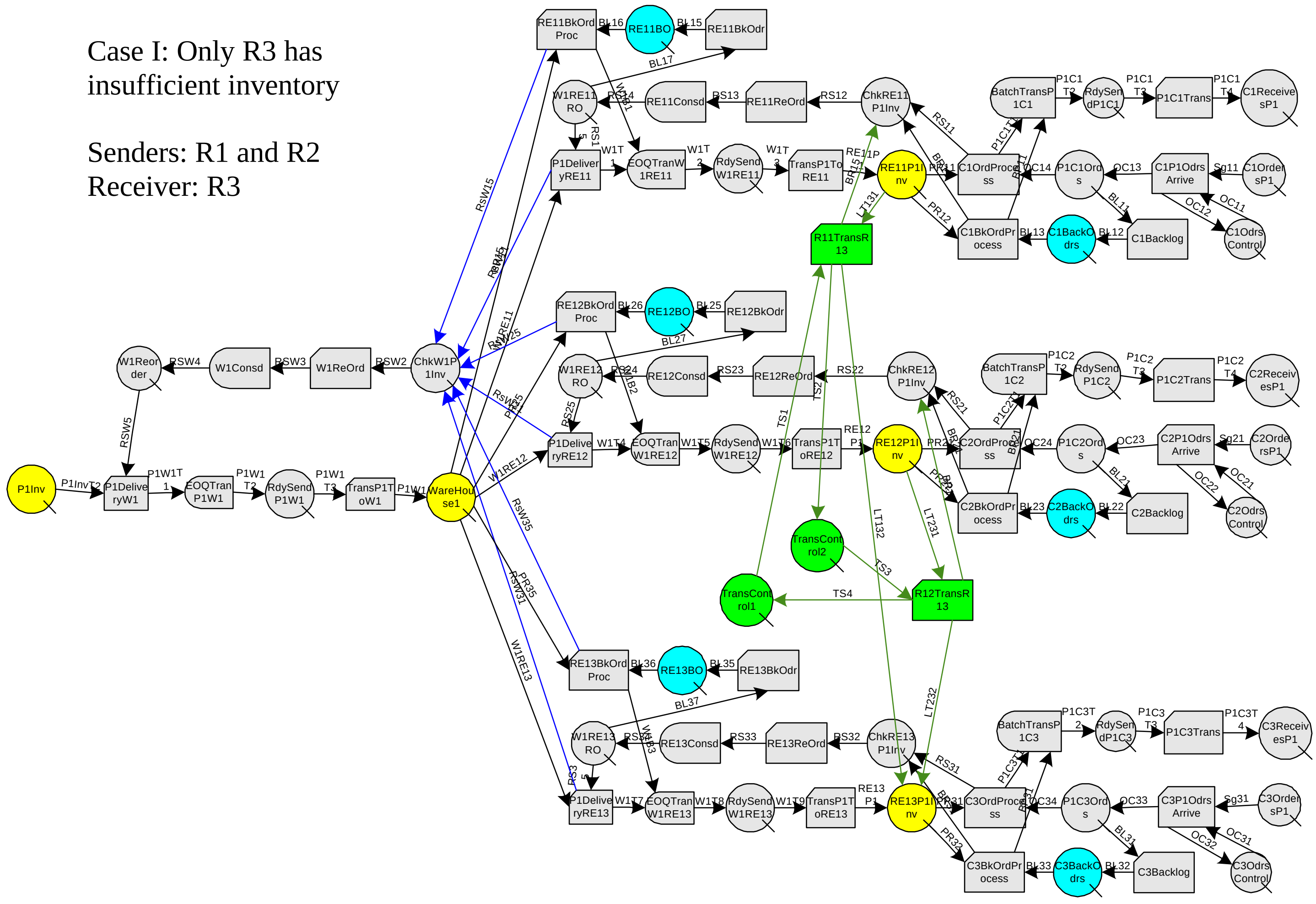


Figure 7.10 Simulation model for a multi-echelon distribution system with installation stock reorder point policy and alternate transshipment policy (Case I)

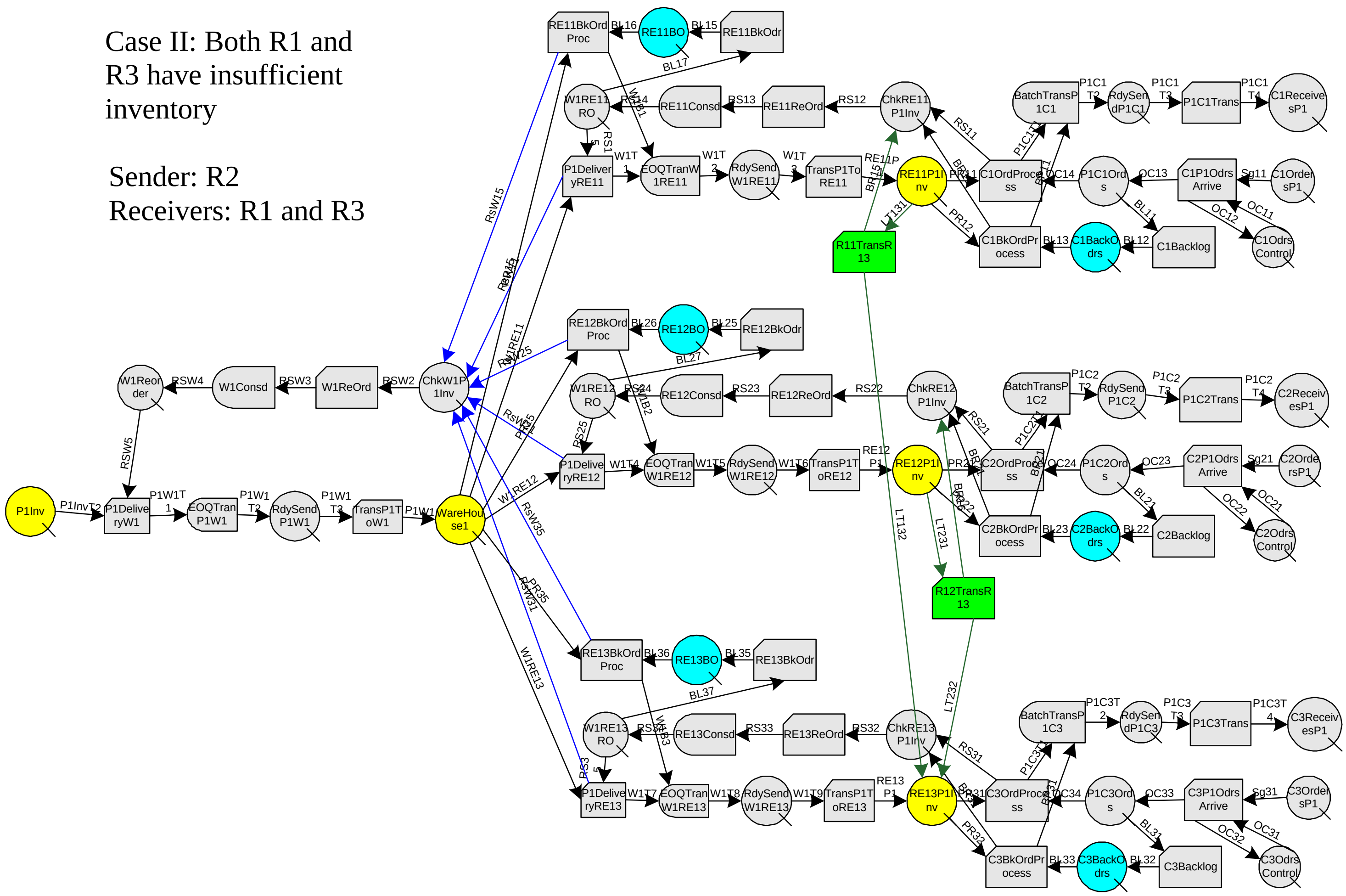


Figure 7.11 Simulation model for a multi-echelon distribution system with installation stock reorder point policy and random transshipment policy (Case II)

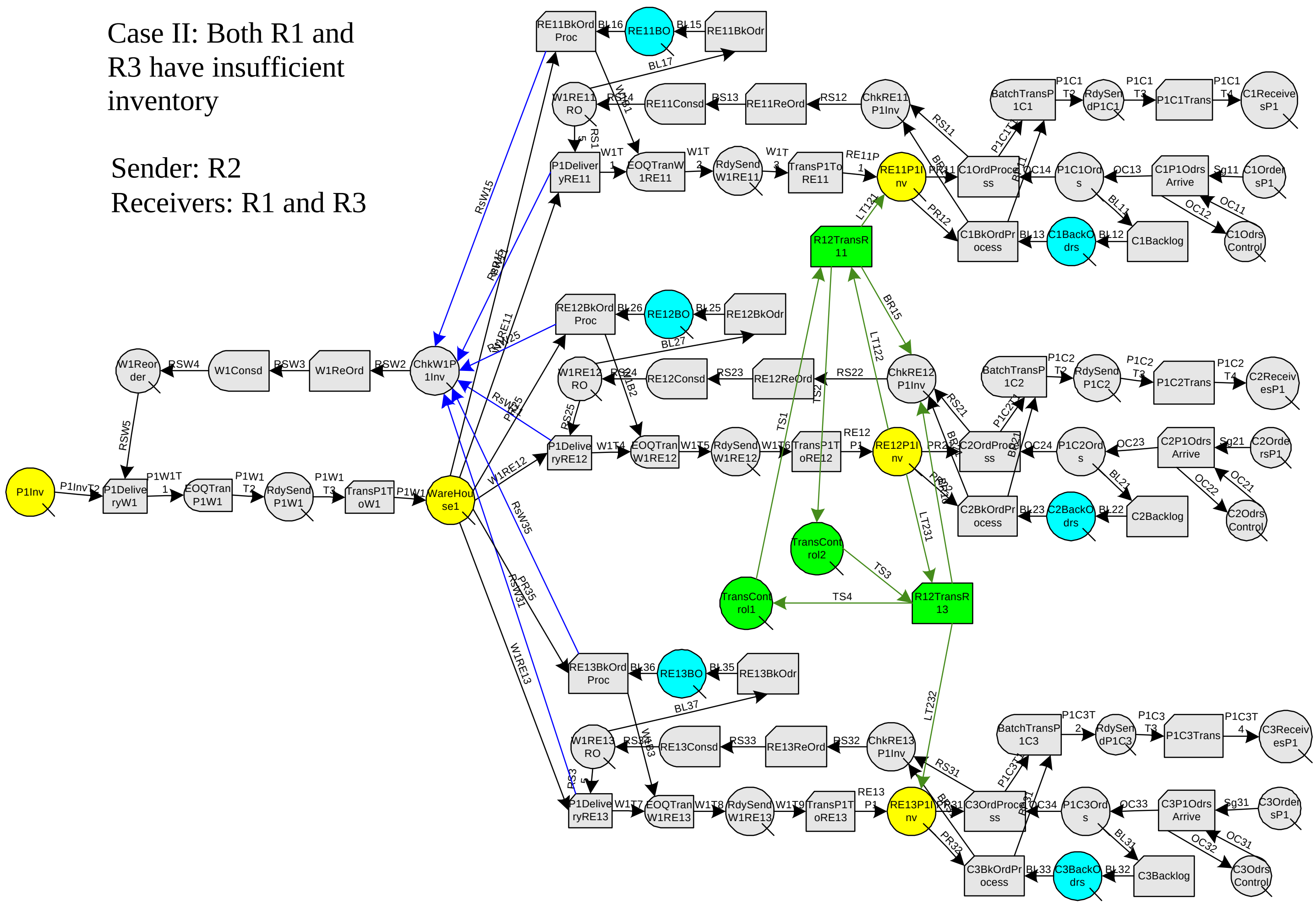


Figure 7.12 Simulation model for a multi-echelon distribution system with installation stock reorder point policy and alternate transshipment policy (Case II)

From the corresponding simulation models, the following performance results can be obtained:

Table 7.5 Costs with different warehouse reorder points for a distribution system with different transshipment policies (Case I)

W1_ReOrderPoints	Random Policy	Alternate Policy	Regular (no transshipment)
4	228294.74	175966.38	237651.38
8	245647.16	148343.34	238801.87
10	230534.43	157234.59	238384.84
12	224913.27	157993.04	242837.31
15	224560.48	141397.59	245474.13
20	273261.01	146140.38	245076.86
25	264802.84	158731.68	252274.62
30	259250.28	157222.57	255144.90
35	269341.03	162011.65	259312.16
38	275891.04	175962.96	259903.95
40	274629.24	165883.67	262485.88
43	278206.78	189995.96	268108.86
45	277806.15	174809.24	270517.50

Correspondingly, we have the plots as shown in Figure 7.13.

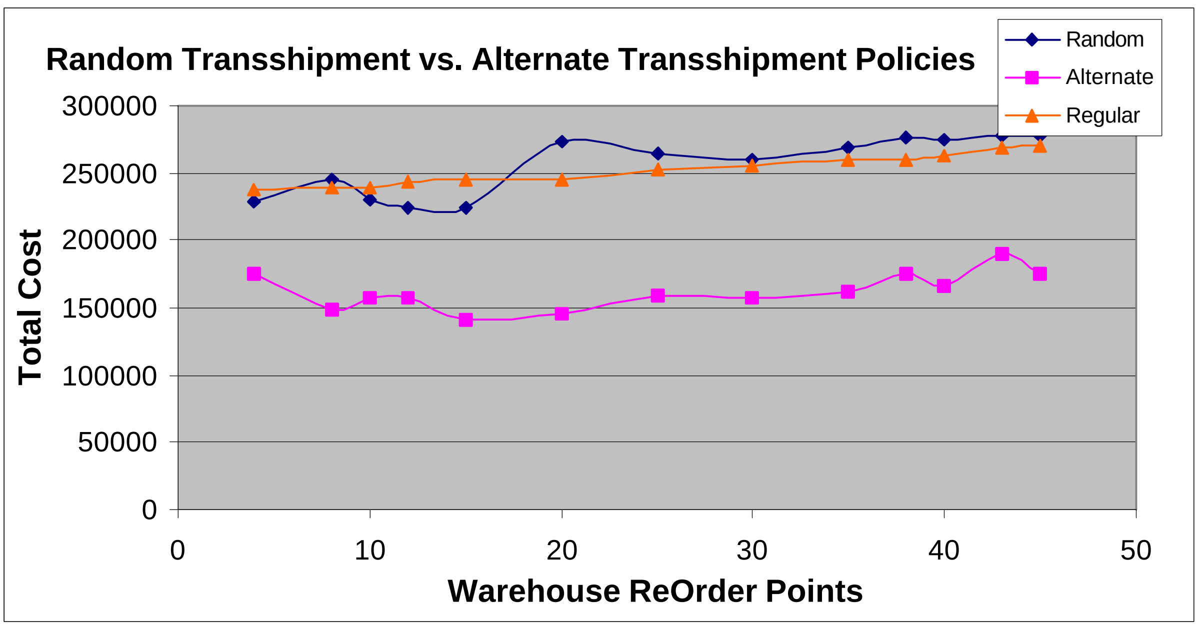


Figure 7.13 Costs with different warehouse reorder points for a distribution system with different transshipment policies (Case I)

The fill-rate performance is given in the following Table.

Table 7.6 Fill rates with different warehouse reorder points for a distribution system with random transshipment policy vs. alternate transshipment policy (Case I)

W1_ReOrderPoints	RA-R1	Alt-R1	RA-R2	Alt-R2	RA-R3	Alt-R3
4	0.752	0.941	0.862	0.963	0.990	0.929
8	0.759	0.939	0.865	0.958	0.992	0.929
10	0.799	0.930	0.885	0.946	0.991	0.930
12	0.776	0.937	0.878	0.951	0.991	0.930
15	0.779	0.912	0.896	0.959	0.991	0.940
20	0.787	0.949	0.882	0.948	0.992	0.945
25	0.828	0.953	0.889	0.995	0.993	0.946
30	0.793	0.926	0.895	0.991	0.994	0.946
35	0.822	0.937	0.898	0.990	0.993	0.947
38	0.817	0.950	0.903	0.987	0.993	0.944
40	0.807	0.955	0.897	0.984	0.993	0.945
43	0.809	0.941	0.887	0.992	0.993	0.947
45	0.817	0.953	0.913	0.991	0.993	0.946

The corresponding fill-rate performance plots are shown in Figure 7.14.

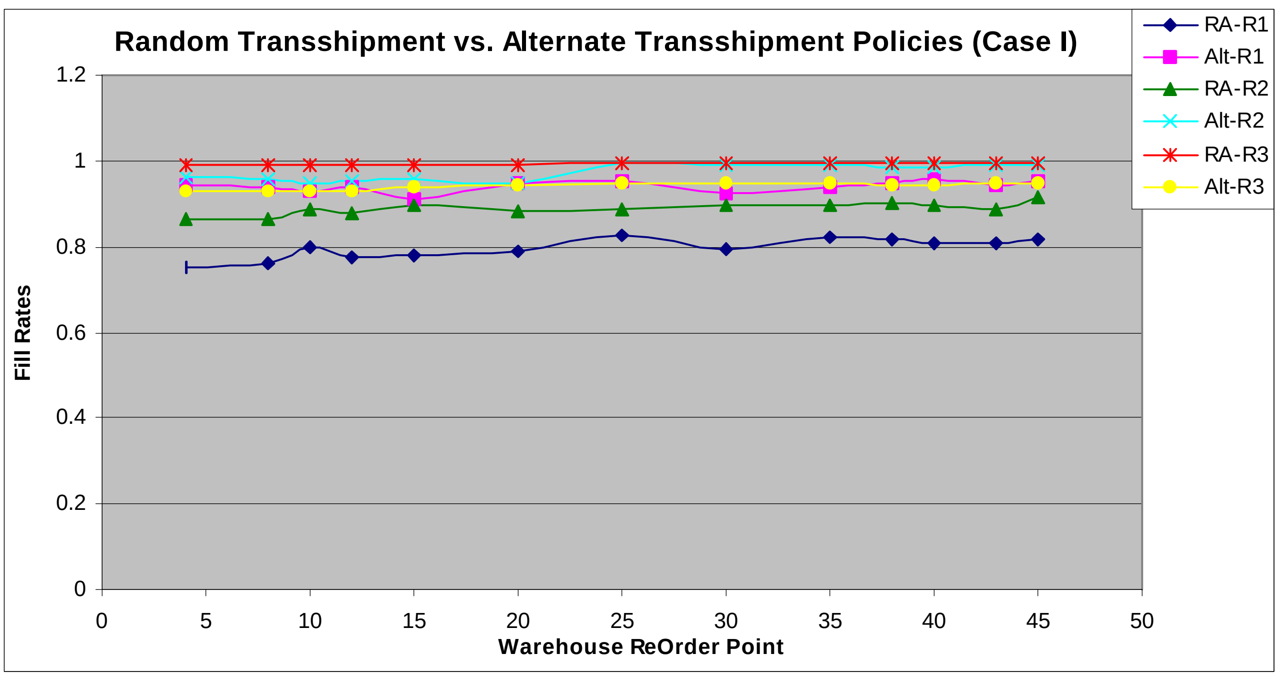


Figure 7.14 Fill rates with different warehouse reorder points for a distribution system with random transshipment policy vs. alternate transshipment policy (Case I)

From above Tables and Figures, we have the following observations: (1) Alternate policy is more cost-effective than regular situation (no transshipment) and random policy. (2) Under random policy, the fill rate of retailer 3 is much better. However, retailer 1 becomes much worse and the fill rates of three retailers are still unbalanced. (3) Under alternate policy, the fill rates of retailers 1 and 2 are still good and the fill rates of three retailers become balanced.

Similarly, for case II, we have the following simulation results (see Tables 7.7, 7.8 and Figures 7.15, 7.16, 7.17, 7.18).

Table 7.7 Costs with different warehouse reorder points for a distribution system with different transshipment policies (Case II)

W1_ReOrderPoints	Random Policy	Alternate Policy	Regular (no transshipment)
4	87971.66	63197.78	78284.40
8	95991.76	61787.65	79120.77
10	90102.48	65609.13	77963.17
12	95167.50	61692.92	77983.61
15	98110.95	68949.24	78300.23
20	98875.31	69539.21	84303.58
25	107687.66	79278.66	91755.61
30	107966.09	80897.76	93117.99
35	109615.01	81600.50	94997.71
38	115765.26	83297.71	100163.20
40	116247.55	82424.05	96697.58
43	118738.99	87169.97	99273.72
45	125469.03	91165.99	102650.03

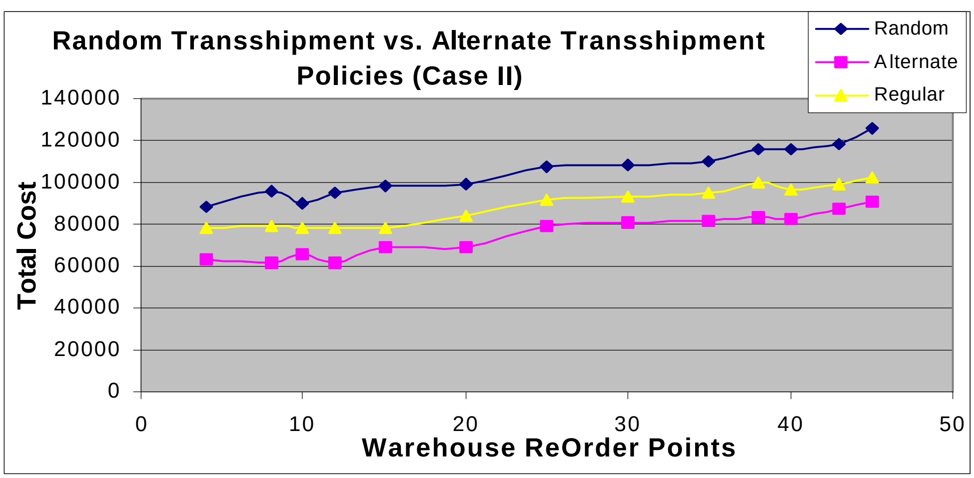


Figure 7.15 Costs with different warehouse reorder points for a distribution system with different transshipment policies (Case II)

Table 7.8 Fill rates with different warehouse reorder points for a distribution system with random transshipment policy vs. alternate transshipment policy (Case II)

W1_ReOrderPoints	RA-R1	Alt-R1	RA-R2	Alt-R2	RA-R3	Alt-R3
4	0.973	0.882	0.800	0.974	0.976	0.756
8	0.977	0.892	0.782	0.966	0.976	0.724
10	0.977	0.881	0.785	0.969	0.975	0.746
12	0.976	0.883	0.796	0.963	0.973	0.774
15	0.977	0.930	0.800	0.963	0.975	0.677
20	0.983	0.895	0.779	0.964	0.974	0.765
25	0.979	0.890	0.859	0.987	0.981	0.839
30	0.982	0.890	0.871	0.992	0.981	0.827
35	0.981	0.902	0.868	0.991	0.984	0.821
38	0.981	0.905	0.879	0.992	0.983	0.839
40	0.981	0.917	0.861	0.991	0.982	0.822
43	0.980	0.908	0.857	0.988	0.982	0.829
45	0.981	0.919	0.862	0.991	0.981	0.835

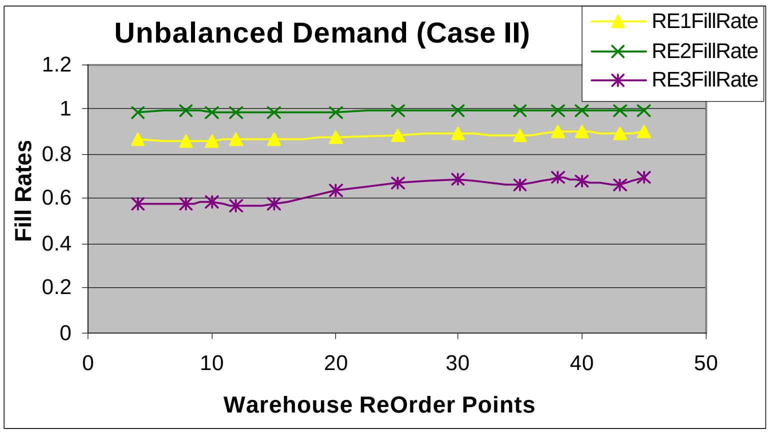


Figure 7.16 Fill rates with different warehouse reorder points for a distribution system without transshipment

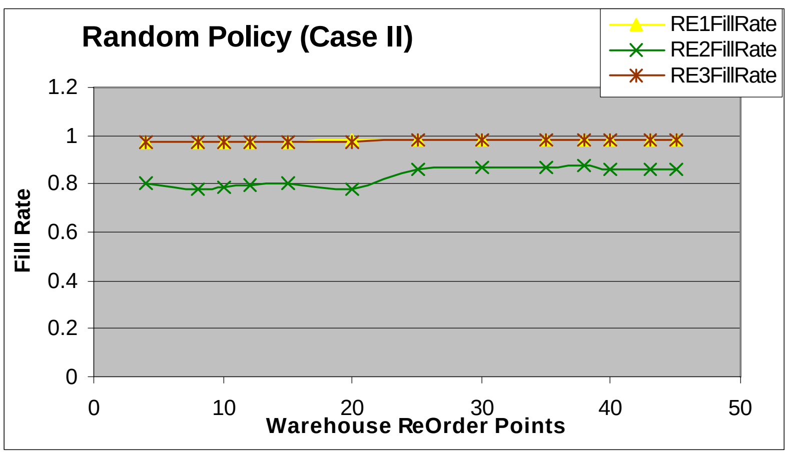


Figure 7.17 Fill rates with different warehouse reorder points for a distribution system with random transshipment policy

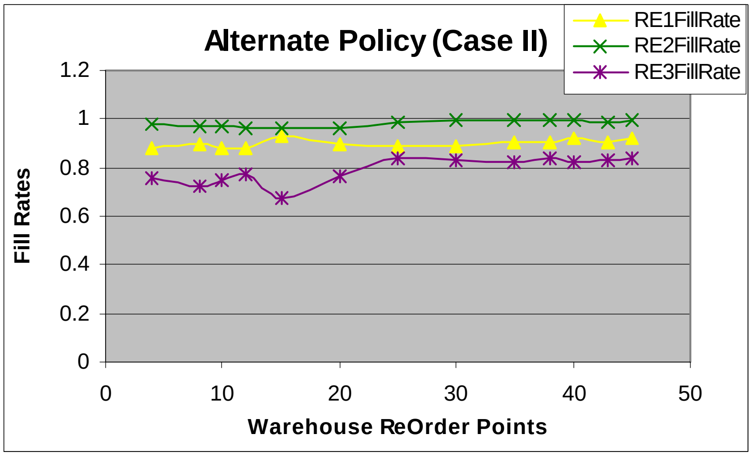


Figure 7.18 Fill rates with different warehouse reorder points for a distribution system with alternate transshipment policy

From above Tables and Figures, the following observations can be obtained: (1) By adopting random transshipment policy, the fill rate of retailer 1 increases by 10%, the fill rate of retailer 3 increases by 34%. The fill rate of retailer 2 decreases by 16%. (2) By changing transshipment mechanism from random policy to alternate policy, the fill rate of retailer 1 increases by 2%, the fill rate of retailer 3 increases by 15%. The fill rate of retailer 2 decreases by 1%.

In summary, the following observations can be obtained from the simulation study for a multi-echelon distribution system:

(1) Depending on the structure of the distribution systems, either echelon stock or installation stock policies may be advantageous.

(2) For Case I (2 senders and 1 receiver), the alternate transshipment policy improves the service levels and reduces the costs.

(3) For Case II (1 sender and 2 receivers), the alternate transshipment policy can provide more balanced service levels and reduce the costs.

7.8 Component Commonality in Integrated Supply Chain Networks

7.8.1 Commonality Index (CI)

The commonality index is a measure of how well the product design utilizes standardized components and is similar to work done by Collier (1981). A component item is any inventory item (including a raw material) other than an end item that goes into higher-level items. An end item is a finished product or major subassembly subject to a customer order. Different from Collier, two types of commonality indexes are defined in this research. One is called component-level (denoted as CI_i), which is to provide an indicator on the percentage of a component being used in different products. The other is called product-level (denoted as CI_p). There are three variables that will affect the commonality index, which are, number of unique components (denoted as *u*), number of total components along the product line (denoted as *c*), and final number of product varieties offered (denoted as *n*). To get the appropriate product-level CI, all these three variables along with component-level CI should be considered. The basic idea is that, by ranking the different component-level CI values, the average for the differences of CI values is computed. Then, this average difference will be multiplied by a weight, which is the ratio of (*c*-*n*) and *u*. A special case appears when all component-level CI values are same, $u<c$ and $u \le n$. In this case, instead of the average difference, product-level CI is obtained by multiplying anyone component-level CI and the weight. Therefore, to calculate CI_p, we first find out the difference between the maximal component-level CI and the minimal component-level CI, which is same as the summation of differences among component-level CI values. Then, we divide the difference by number of unique components to get the average CI difference. Finally, the average CI difference is multiplied by (*c*-*n*) so that the information on how broad the components spread in product line is captured.

The following formula is used to calculate the component-level CI:

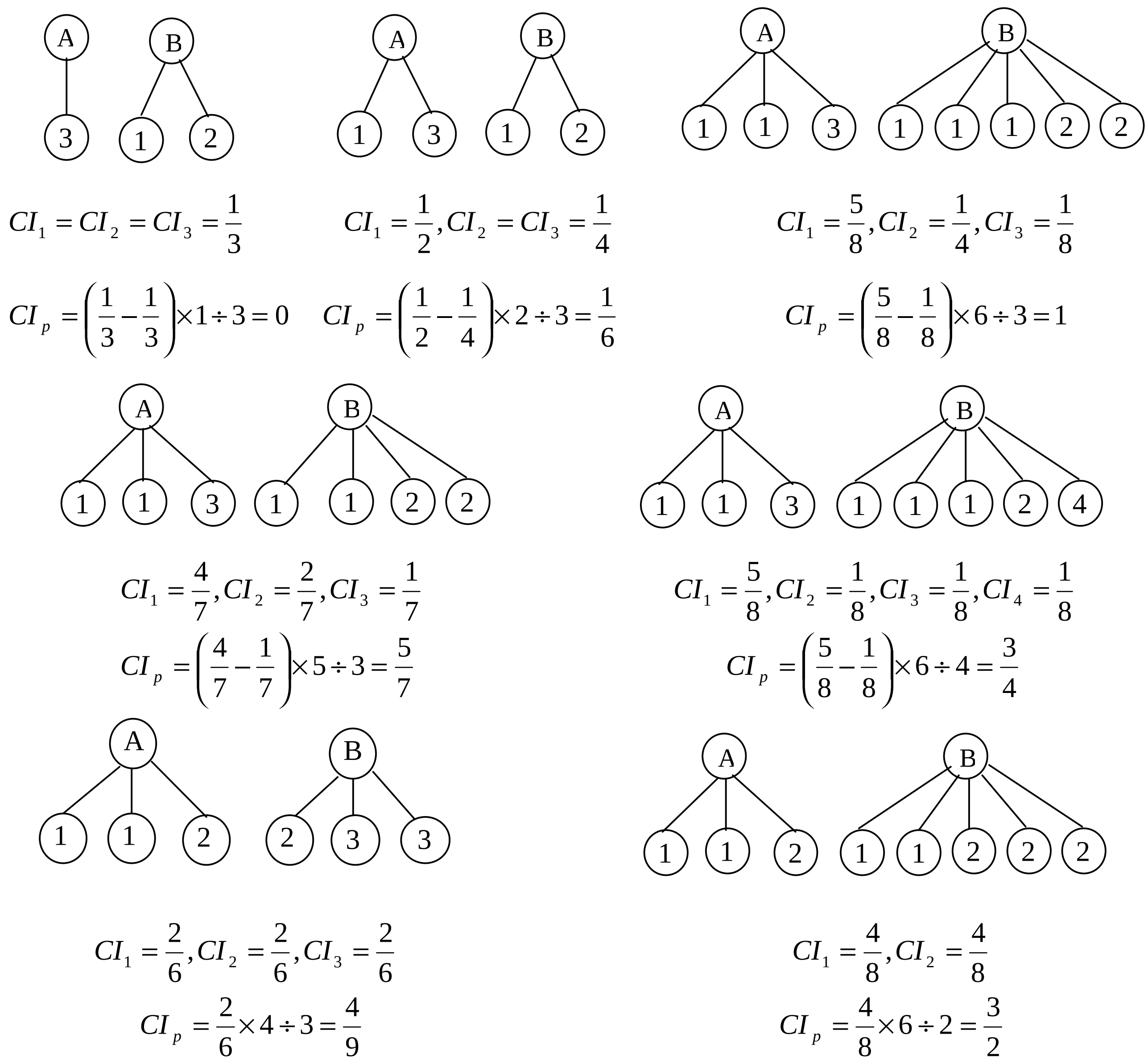
$$CI_i = \frac{\sum_j f_{ij} \cdot d_j}{\sum_{i,j} f_{ij} \cdot d_j} \qquad (7\text{-}13)$$

f_{ij} = number of component i in product j

d_j = demand of product j

$0 \le CI_i \le 1$

The lower bound of the component-level CI is 0 (no commonality). The upper bound on the degree of commonality is 1. Complete commonality results when the total number of distinct components (u) equals one.



$$CI_1 = CI_2 = CI_3 = \frac{1}{3} \qquad CI_1 = \frac{1}{2}, CI_2 = CI_3 = \frac{1}{4} \qquad CI_1 = \frac{5}{8}, CI_2 = \frac{1}{4}, CI_3 = \frac{1}{8}$$

$$CI_p = \left(\frac{1}{3} - \frac{1}{3}\right) \times 1 \div 3 = 0 \qquad CI_p = \left(\frac{1}{2} - \frac{1}{4}\right) \times 2 \div 3 = \frac{1}{6} \qquad CI_p = \left(\frac{5}{8} - \frac{1}{8}\right) \times 6 \div 3 = 1$$

$$CI_1 = \frac{4}{7}, CI_2 = \frac{2}{7}, CI_3 = \frac{1}{7} \qquad CI_1 = \frac{5}{8}, CI_2 = \frac{1}{8}, CI_3 = \frac{1}{8}, CI_4 = \frac{1}{8}$$

$$CI_p = \left(\frac{4}{7} - \frac{1}{7}\right) \times 5 \div 3 = \frac{5}{7} \qquad CI_p = \left(\frac{5}{8} - \frac{1}{8}\right) \times 6 \div 4 = \frac{3}{4}$$

$$CI_1 = \frac{2}{6}, CI_2 = \frac{2}{6}, CI_3 = \frac{2}{6} \qquad CI_1 = \frac{4}{8}, CI_2 = \frac{4}{8}$$

$$CI_p = \frac{2}{6} \times 4 \div 3 = \frac{4}{9} \qquad CI_p = \frac{4}{8} \times 6 \div 2 = \frac{3}{2}$$

Figure 7.19 Computational examples for the degree of commonality index

The product-level CI is computed as follows:

$$CI_p = \begin{cases} \dfrac{CI_i}{u} \times (n-c), & when \quad \max_i\{CI_i\} = \min_i\{CI_i\} \quad and \quad c > u \quad and \quad u \le n \\ \left[\dfrac{\left(\max_i\{CI_i\} - \min_i\{CI_i\}\right)}{u}\right] \times (n-c), & otherwise \end{cases} \tag{7-14}$$

u = number of unique components

n = final number of product varieties offered

c = total number of components along the product line

In general, a higher CI is better since it indicates that the different varieties within the product family are being achieved with more common components.

Figure 7.19 illustrates the use of the CI measures for five sets of two end products (labeled as A and B). Calculation of the CI is shown below each case. Here, we assume that all demands of products are same, i.e., $d_1 = d_2$.

7.8.2 Impact of Component Commonality on Integrated Supply Chain Performance

The purpose of the simulation study is to evaluate the performance of "integrated supply chain with component commonality" versus "integrated supply chain without component commonality." The simulation model for an integrated supply chain network with echelon stock policy and commonality index of 1 is shown in Figure 7.20. This simulation model is a comprehensive model since it contains raw material procurement, manufacturing processes, assembly operations, warehousing, and distribution functions. The corresponding source code and output are given in Appendix B.

Three different performance measures are employed in the experiment: order fill rate, delivery time and total cost. The experimental results for fill rate, delivery time, total cost and resource utilization rate are summarized in Table 7.9.

Table 7.9 Simulation results for fill rate, delivery time, and resource utilization rate

CI	Replications	Delivery Time	R1 Fill Rate	R2 Fill Rate	R3 Fill Rate	M1UtilRate	M2UtilRate	M3UtilRate
1	**1**	4223.63	0.918	0.952	0.918	0.981	0.952	0.901
	2	4250.13	0.882	0.963	0.940	0.976	0.947	0.903
	3	4222.55	0.915	0.964	0.897	0.981	0.952	0.867
	4	4230.74	0.911	0.956	0.934	0.979	0.950	0.917
	5	4240.48	0.881	0.952	0.942	0.977	0.949	0.911
	…	**…**	**…**	**…**	**…**	**…**	**…**	**…**
	496	4175.87	0.918	0.939	0.971	0.991	0.962	0.888
	497	4207.11	0.960	0.953	0.888	0.984	0.956	0.889
	498	4228.98	0.929	0.966	0.888	0.980	0.952	0.879
	499	4260.51	0.934	0.960	0.888	0.973	0.944	0.899
	500	4249.00	0.956	0.945	0.916	0.976	0.947	0.916
	Mean	4239.24	0.920	0.955	0.919	0.978	0.948	0.901
	SD	146.91	0.107	0.044	0.105	0.031	0.030	0.068
1/6	**1**	8288.54	0.840	0.909	0.838	0.991	0.958	0.839
	2	8284.00	0.844	0.883	0.873	0.991	0.959	0.840
	3	8290.37	0.850	0.908	0.834	0.991	0.959	0.838
	4	8286.03	0.844	0.927	0.811	0.991	0.959	0.840
	5	8286.22	0.815	0.914	0.865	0.991	0.958	0.840
	…	**…**	**…**	**…**	**…**	**…**	**…**	**…**
	496	8294.76	0.846	0.927	0.819	0.991	0.958	0.838
	497	8287.80	0.838	0.913	0.834	0.991	0.958	0.839
	498	8290.99	0.828	0.941	0.819	0.991	0.958	0.838
	499	8285.17	0.859	0.871	0.872	0.991	0.958	0.839
	500	8298.49	0.803	0.923	0.848	0.991	0.957	0.837
	Mean	8294.51	0.816	0.939	0.829	0.991	0.958	0.838
	SD	18.14	0.072	0.069	0.077	0.001	0.003	0.003
0	**1**	10211.95	0.758	0.908	0.775	0.686	0.778	1.000
	2	10208.29	0.728	0.904	0.785	0.686	0.778	1.000
	3	10198.74	0.761	0.895	0.761	0.687	0.779	1.000
	4	10206.93	0.762	0.907	0.767	0.686	0.779	1.000
	5	10202.91	0.760	0.904	0.778	0.687	0.778	1.000
	…	**…**	**…**	**…**	**…**	**…**	**…**	**…**
	496	10212.09	0.745	0.906	0.767	0.685	0.777	1.000
	497	10208.49	0.722	0.896	0.802	0.686	0.778	1.000
	498	10202.85	0.747	0.902	0.802	0.686	0.779	1.000
	499	10203.70	0.763	0.894	0.781	0.686	0.778	1.000
	500	10201.42	0.746	0.918	0.772	0.686	0.779	1.000
	Mean	10210.21	0.740	0.907	0.786	0.686	0.778	1.000
	SD	29.80	0.057	0.031	0.071	0.002	0.003	0.000

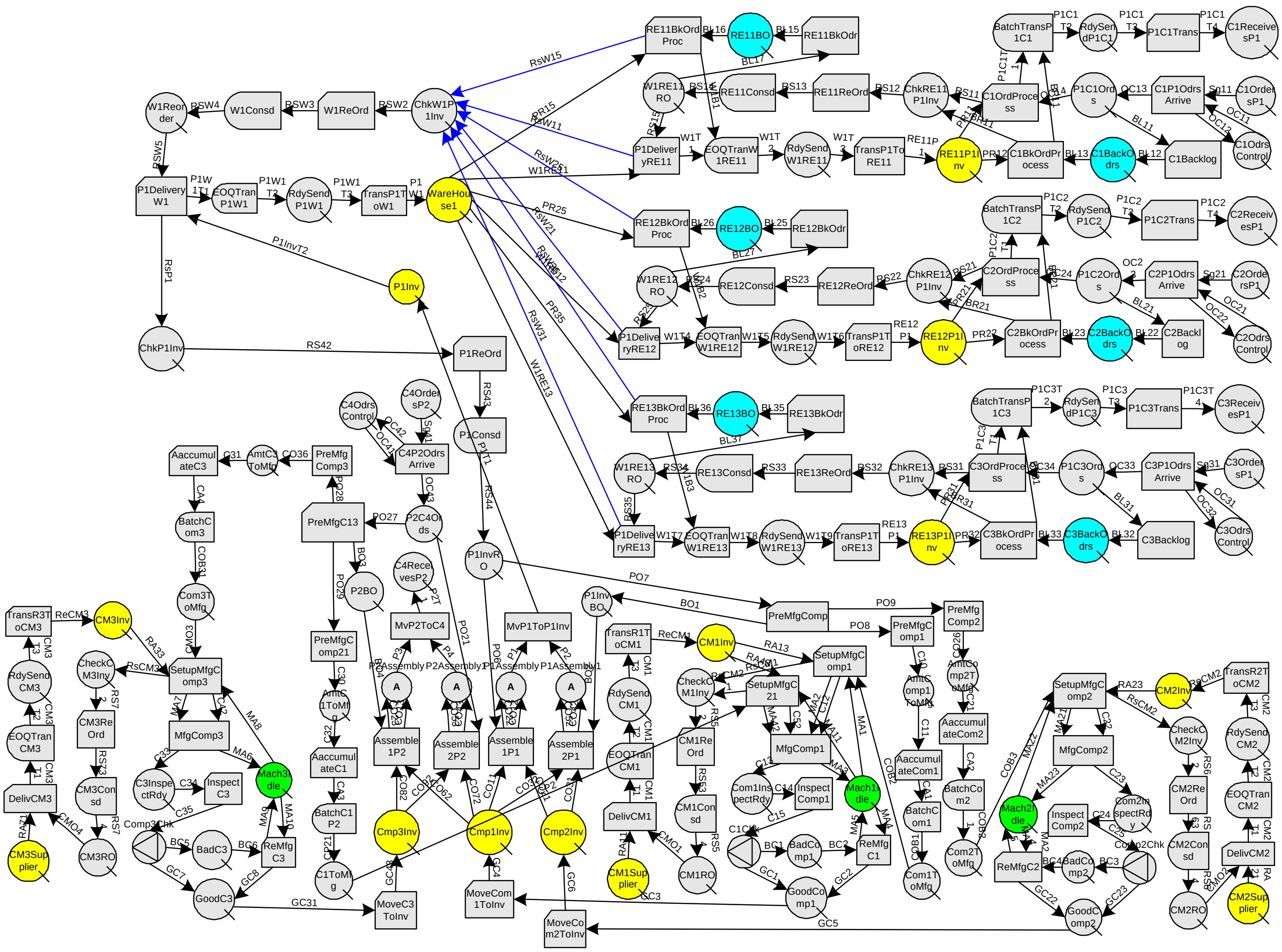


Figure 7.20 Simulation model for an integrated supply chain network with echelon stock policy and commonality index of 1

For each performance measurement, an analysis of variance (ANOVA) is conducted to compare the performance of "integrated supply chain with different component commonality indexes" and "integrated supply chain without component commonality." Here, the performance measures include delivery time and fill rates for different retailers. In the ANOVA, the level of confidence is set as $\alpha = 0.05$.

H_0: $m_1 = m_2 = m_3$.

H_1: *At least two of the means are not equal.*

The ANOVA are conducted as follows:

(1) Analysis-of-variance for delivery time

Table 7.10 Analysis-of-variance for delivery time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
CI=1	500	2114450	4228.9	594.0537555
CI=1/6	500	4144618.5	8289.237	20.70920108
CI=0	500	5102868.5	10205.737	20.28362331

ANOVA

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	*Computed f*	*P-value*	*f critical*
Between Groups	186272964.43	2	93136482.21	439982.602	1.18E-61	3.00
Within Groups	316888.24	1497	211.6821933			
Total	186589852.67	1499				

Decision: Since $P<0.05$, or computed $f > f_{critical}$, reject H_0 and conclude that the average delivery time are not all the same.

However, we still don't know which of the delivery-time means are equal and which are different. We need to perform the further multiple comparison tests. Here, we adopt Tukey's test (Walpole et al., 1997). This test allows formation of simultaneous $100(1-\alpha)\%$ confidence intervals for all paired comparisons. The method is based on the studentized range distribution.

From the analysis-of-variance table, we know that the error mean square is $s^2 = 211.68$ (1497 degrees of freedom). The sample means are given by (ascending order):

4239.24, 8294.51, 10210.21

With $\alpha = 0.05$, the value of $q(0.05, 3, 1497) = 3.32$. Thus all absolute differences are to be compared to

$$3.32\sqrt{\frac{211.68}{500}} = 2.16$$

As a result, the following represent means found to be significantly different using Tuksy's procedure:

1 and 2, 2 and 3, 1 and 3.

Therefore, we conclude that the delivery time of integrated supply chain with higher commonality index is significantly (with 95% C.I.) less than that of integrated supply chain with lower commonality index.

(2) Analysis-of-variance for retailers' fill rates

Table 7.11 Analysis-of-variance for retailer 1's fill rate

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
CI=1	500	460.2	0.9204	0.00069449
CI=1/6	500	418.35	0.8367	0.00028468
CI=0	500	374.6	0.7492	0.00021218

ANOVA

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	*Computed f*	*P-value*	*f critical*
Between Groups	0.146571267	2	0.073285633	184.545201	1.8E-16	3.00
Within Groups	0.59	1497	0.000397115			
Total	0.74	1499				

Decision: Since $P<0.05$, or computed $f > f_{critical}$, reject H_0 and conclude that the average fill rate for retailer 1 is not all the same.

The Tukey's test is conducted as follows.

From the analysis-of-variance table, we know that the error mean square is $s^2 = 0.000397$ (1497 degrees of freedom). The sample means are given by (ascending order):

0.74, 0.816, 0.92

With $\alpha = 0.05$, the value of $q(0.05, 3, 1497) = 3.32$. Thus all absolute differences are to be compared to

$$3.32\sqrt{\frac{0.000397}{500}} = 0.00296$$

As a result, the following represent means found to be significantly different using Tuksy's procedure:

1 and 2, 2 and 3, 1 and 3.

Similarly, for retailer 2, we have:

Table 7.12 Analysis-of-variance for retailer 2's fill rate

Anova: Single Factor

SUMMARY

Groups	***Count***	***Sum***	***Average***	***Variance***
CI=1	500	477.5	0.955	7.4444E-05
CI=1/6	500	455.8	0.9116	0.00044027
CI=0	500	451.7	0.9034	5.2267E-05

ANOVA

Source of Variation	***Sum of Squares***	***Degrees of Freedom***	***Mean Square***	***Computed f***	***P-value***	***f critical***
Between Groups	0.015377867	2	0.007688933	40.6837815	7.1E-09	3.00
Within Groups	0.283	1497	0.000188993			
Total	0.298	1499				

Decision: Since *P<0.05*, or computed $f > f_{critical}$, reject H_0 and conclude that the average fill rate for retailer 2 is not all the same.

The Tukey's test is conducted as follows.

From the analysis-of-variance table, we know that the error mean square is s^2= 0.000189 (1497 degrees of freedom). The sample means are given by (ascending order):

0.907, 0.939, 0.955

With α = 0.05, the value of *q*(0.05, 3, 1497) = 3.32. Thus all absolute differences are to be compared to

$$3.32\sqrt{\frac{0.000189}{500}} = 0.00204$$

As a result, the following represent means found to be significantly different using Tuksy's procedure:

1 and 2, 2 and 3, 1 and 3.

For retailer 3, we have:

Table 7.13 Analysis-of-variance for retailer 3's fill rate

Anova: Single Factor

SUMMARY

Groups	***Count***	***Sum***	***Average***	***Variance***
CI=1	500	459.1	0.9182	0.00080773
CI=1/6	500	420.65	0.8413	0.00050934
CI=0	500	389.5	0.779	0.00019733

ANOVA

Source of Variation	***Sum of Squares***	***Degrees of Freedom***	***Mean Square***	***Computed f***	***P-value***	***f critical***
Between Groups	0.097238467	2	0.048619233	96.313147	5.1E-13	3.00
Within Groups	0.756	1497	0.000504804			
Total	0.853	1499				

Decision: Since $P<0.05$, or computed $f > f_{critical}$, reject H_0 and conclude that the average fill rate for retailer 3 is not all the same.

The Tukey's test is conducted as follows.

From the analysis-of-variance table, we know that the error mean square is $s^2 = 0.0005048$ (1497 degrees of freedom). The sample means are given by (ascending order):

0.786, 0.829, 0.919

With $\alpha = 0.05$, the value of $q(0.05, 3, 1497) = 3.32$. Thus all absolute differences are to be compared to

$$3.32\sqrt{\frac{0.0005048}{500}} = 0.003336$$

As a result, the following represent means found to be significantly different using Tuksy's procedure:

1 and 2, 2 and 3, 1 and 3.

From the above analysis, it can be shown that the fill rates of retailers 1, 2 and 3 of the integrated supply chain with higher commonality index are significantly (with 95% C.I.) higher than those of retailers 1, 2 and 3 of the integrated supply chain with lower commonality index, respectively.

Therefore, the fill rates of integrated supply chain with higher commonality index are significantly (with 95% C.I.) higher than those of integrated supply chain with lower commonality index. Furthermore, the relative benefits from component commonality increase with the difference of commonality index values for two supply chain commonality configurations.

(3) Resource utilization rates

By comparing the machines' utilization rates for the network configurations with different degree of commonality (see Table 7.9), it can be shown that the integrated supply network with higher commonality index will generate more balanced machines' utilization rates than the one with lower commonality index.

7.9 Simulation Model Verification and Validation

7.9.1 Verification

The purpose of simulation model verification is to build the model right. In this research, verification is achieved by following steps:

1. Translation of conceptual model into simulation model (logic flowcharts);
2. Simulation program performs as intended (debugging in modules or subprograms, trace);
3. Graphical representation by STROBOSCOPE;
4. Examine the output for reasonableness under a variety of settings; and
5. Compare the output with the analytic results under simple assumptions.

7.8.2 Validation

The goal of simulation validation is to build the right model. The following model validation steps are employed in this research:

1. Examine whether or not the simulation models are accurate representations of the system under study;
2. Examine whether or not the decisions based on the simulation models are consistent with the decisions based on the physical system. For instance, if the variance of warehouse replenishment lead time increases, then the safety stock and reorder point should also increase.