6.1 Summary of Work Done

Supply Chain Management (SCM) is a pertinent area for the research especially for those who deal with interdisciplinary areas of management. A detailed study on SCM was conducted as a first step to this research which includes the overall concept of Supply Chain (SC), strategic role and responsibilities of each member in an SC, key drivers and obstacles of SC and various issues of coordination with appropriate methodologies to solve it. This study revealed the importance of supply chain coordination (SCC) without which complete success of SCM cannot be achieved in any industry. Further study on SCM with a special reference to SCC was then conducted as the next step for the in-depth analysis. The literature review on SCC revealed various issues still to be addressed. From literature, it was also found that different categories of mechanisms were used to solve some of the SCC issues. Finally, it was decided to concentrate on how to improve the performance of SC by implementing selected coordination mechanisms separately and jointly under various operating conditions of SC. The SCC issues addressed in this study are order quantity, back order, lost sales, inventory, customer service level,
bullwhip effect and finally the overall performance indicated by SC profit (surplus)/cost.

After literature review, the topic for research was decided as “study of supply chain coordination and mechanisms to improve its performance”. The research was further focused on the study of the performance of a three level SC consisting of one player at each level (supplier- manufacturer- retailer) facing price dependent demand with price discount and delay in payment simultaneously being used as coordination mechanisms. This study used mathematical modelling. The cost and revenue parameters of each player in the supply chain were formulated and then the profit function of each player was derived. Finally, a mathematical model for the overall profit of the three-level SC was developed. The data obtained from a standard problem in literature was used to solve the model using ‘Excel solver’. Sensitivity analysis was also conducted. The results showed that the performance of SC (SC profit) increases significantly on implementing the coordination mechanisms simultaneously, as against the individual case of ‘price discount alone’ and ‘no coordination’.

The three level SC considered in mathematical modelling was then extended to a three level networked SC consisting of four retailers, two wholesalers, and a manufacturer with an infinite parts supplier. The customer demand and lead time were made probabilistic in this part of the study. Price discount and delay in payment are used as coordination mechanisms as in mathematical modelling. The combined and individual effect of price discount, delay in payment on the performance of this network SC under lost sale and backorder cases were studied using simulation modelling. Two separate products were taken for the study under lost sale and backorder. The input data for this study was obtained from the industry to make the study a realistic one. The simulation modelling was done using the simulation software “Arena”. The
simulation was run for each case of ‘no coordination’ (no coordination mechanisms are used) and ‘coordination’ (using ‘price discount’ and ‘delay in payment’ as coordination mechanisms separately and jointly). The simulation results showed that the SC performance (profit) significantly improved in each case of coordination in the individual case of price discount and delay in payment compared to ‘no coordination’. The profit increased further in the case of combination of price discount and delay in payment. A sensitivity analysis was also conducted as a part of this study.

In continuation of the above, a study on the performance of a four-level SC consisting of a manufacturer, a wholesaler, a distributor and a retailer with ‘information sharing’ as coordination mechanism under lost sale and backorder cases using a simulation game with live players was conducted. This simulation study was conducted using software called ‘Supply Chain Role Play Game’ (SCRPG) developed at NIT, Calicut by Pamulety and Pillai (2010). This simulation game was conducted with the help of a group of well trained students having knowledge of SCM who performed the role of each player in the SC and played using a network of five computers including the server system. Experiments were conducted using the simulation game with different types of information sharing cases such as traditional method, point of sales data, forecast demand, actual customer demand, demand and supply chain performance (latest period demand, latest period demand met, latest period inventory of each stage, and order quantity). The results show that the maximum SC performance is obtained while sharing ‘demand and supply chain performance (D&SCP)’ and the minimum under ‘traditional’ way of doing business. As part of this study, statistical tests were also conducted to analyse the statistical significance of the difference found between the performances of SC corresponding to various types of information sharing.
6.2 Limitations of the Study

This research work is conducted to study the performance of a multi-level SC using selected coordination mechanisms under dynamic operating conditions. The input data also were collected from the industry to make the study a realistic one to the extent possible. But, the models used were having many constraints which move them away from reality to some extent. The following limitations are listed out as far as this study is concerned.

- Limited to a four level SC with maximum four players at a level
- Limited to certain types of information sharing (IS)
- Uncertainty is limited to demand and lead time
- Limited to two category of mechanisms (supply chain contracts & IS)
- Sourcing & logistic part are not considered
- All revenue/costs items are not considered
- Production & storage capacity constraints are not considered
- Single product case only considered
- Profit/cost only was used to measure performance

6.3 Major Findings and Discussion

The study on the performance of three-level SC with price discount and delay in payment jointly as coordination mechanisms using mathematical modelling was conducted for various cases of delay in payment as follows. i) permissible delay in payment is maximum up to buyer’s inventory cycle time and no extension allowed ii) delay in payment availed by the buyer (with interest for the additional period that exceeds the permitted one) is greater than the permissible delay in payment but both (permissible and availed) are
maximum up to buyer’s inventory cycle time iii) delay in payment availed by the buyer (with interest for the additional period that exceeds the permitted one) is greater than or equal to and permissible delay in payment is less than or equal to, the buyer’s inventory cycle time. The analysis showed that the SC profit increases in the second case compared to the first case and further increases in the third case compared to the second case. It is found that the reason for this increase in profit in second case and further increase in third case (where the delay in payment availed is more than the inventory cycle time) is as follows i) the reduction net inventory carrying cost due to both reduction in holding cost and increase in end customer demand since the demand is price elastic ii) the increase in net savings due to more time and money available for investment due to the increase in inventory cycle time. The amount of increase in profit in the second and the third case is 0.12% and 0.51% respectively. So, the third case is used for the rest of the analysis in this part of the study. The SC profit increases while using ‘price discount’ alone compared to ‘no coordination’ and further increased when using ‘price discount’ & ‘delay in payment’ jointly compared to price discount alone. The results showed that the amount of increase in SC profit in the case of ‘price discount’ alone and combination of ‘price discount’ and ‘delay in payment’ is 1.44% and 2.49% respectively compared to ‘no coordination’. Another important finding is that the optimal value of interest free permissible delay in payment permitted by the supplier to the manufacturer is obtained as zero in the second and third case as supplier does not get any delay in payment from its upstream player in this study which affects the supplier in second and third case. The optimal value of price discount is obtained as minimum (zero) for supplier and maximum (20.61) for retailer in the third case (maximum SC profit case). The reasons for these results are also same as above i.e., supplier is not getting any discount from its upstream player and the discount given by the retailer decides the end customer
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demand respectively. Sensitivity analysis revealed the effect of various system parameters on SC profit. The analysis showed that the effect of the rate of return of manufacturer affects the SC profit more, compared to other players in this study. This is because the manufacturer is getting the chance to invest the amount to be paid to the supplier and at the same time to receive the interest from the retailer for delaying the payment. But, the retailer has no opportunity to get the interest due to delay in payment from its downstream player even though he has the opportunity to invest the amount to be paid to the manufacturer and Similarly, supplier has the opportunity to receive the interest from the manufacturer but no opportunity to delay the payment to its upstream player and to make the investment. Sensitivity analysis also showed that the order cost of retailer plays a major role on the SC profit as it is very crucial in deciding the order quantity of other players in this study. As price elasticity increases, the SC profit in the case of combination of ‘price discount’ and delay in ‘payment’ increases compared to the case of ‘price discount’ alone but the rate decreases. This shows that the effect of a combination of these mechanisms on SC profit is relatively less at higher elasticity of demand.

The results obtained from the simulation of network SC for various cases of coordination and no coordination show that the SC profit enhanced significantly due to coordination under both lost sale and backorder cases. The Standard Deviation (SD) of the profit values obtained from the 20 simulation runs is seen to vary from 0.3 to 0.7 % of the mean. The SD being so small implies that, for all practical purposes the mean has been taken as the performance measure. Therefore the change in performance from one case to the next case of use of coordination could be judged from change in mean profit figures of each case. The maximum increase in profit is found in the case of a combination of price discount and delay in payment under both lost sale (10.01%) and backorder (7.85%) compared to ‘no coordination’. The increase
in SC profit in the case of price discount and delay in payment is 2.10% and 6.53% respectively under lost sale compared to ‘no coordination’. Similarly, the increase in profit in the case of price discount, delay in payment is 3.09%, 4.06% respectively under backorder compared to ‘no coordination’. It is also found that increase in SC profit is relatively high in the case of ‘delay in payment’ compared to the case of price discounts under both the cases. This is due to the decrease in total order cost of each player because of increase in order quantity of the retailer and others as well due to reduction in holding cost in the case of delay in payment compared to other mechanism. This improvement in performance in the individual case of ‘delay in payment’ compared to price discount alone cannot be generalized as the performance of price discount depends on the price elasticity of demand also. The in-depth analysis shows that the manufacturer profit (the upstream player in the network SC) is reduced, compared to others owing to coordination, especially in the case of price discount alone. This is due to the fact that the manufacturer is not getting any discount or delay in payment from his upstream player and the manufacturer sacrifices for the overall benefit of SC. Since the overall SC profit increases owing to coordination, the decrease in profit for the manufacturer under coordination can be compensated by proper profit sharing methodology among players to get equal rate of return for each player based on their investment. The analysis also showed that individual hike in profit in the case of the wholesaler and the retailer due to coordination is significantly high under both lost sale and backorder. It is also found that the increase in profit for various cases of coordination is high in the case of lost sale compared to backorder. So, the effect of ‘delay in payment’ and combination of ‘price discount’ and ‘delay in payment’ on SC profit is relatively high in the case of lost sale as the amount of reduction in cost is relatively high compared to backorder.

It is seen from the sensitivity analysis that Rs.3 and Rs.3000 are the optimal value of ‘price discount’ under lost sale and backorder respectively in
the case used in this study. Sensitivity analysis also showed that there is a proportional change in SC profit with change in rate of return of any player. Therefore, the rate of return should be kept at the highest possible level by each player. The in-depth analysis revealed that the rate of return of the wholesaler and the retailer affects more on SC profit, compared to the manufacturer under lost sale and under backorder. The sensitivity analysis on price elasticity showed that the SC profit is increasing with a rise in price elasticity and the rate of increase in profit is almost constant for both lost sale and backorder cases. However, it is found that the rate of increase in SC profit is consistently higher in backorder case. The analysis on various cases of order cost showed that the mutual interchange of order cost between the wholesaler and the manufacturer does not make any change in SC profit, provided order cost of retailer remains same. It is also found that when the order cost of the retailer is reduced, the optimum value of discount is also reduced and it remains same in all other cases. The overall analysis on order cost showed that the order cost of the retailer plays a major role, as it decides the order quantity of the retailers and other players in this study. These findings on order cost are the same under both lost sale ad backorder cases. Sensitivity analysis on delay in payment revealed that change in permissible delay in payment given by the manufacturer to the wholesaler affects SC profit more, compared to the change in permissible delay in payment given by the wholesaler to the retailer in this study. It is also found that the change in delay in payment availed by the wholesaler from the manufacturer affects SC profit more, compared to the change in delay in payment availed by the retailer from the wholesaler. Another finding on delay in payment is that the change in permissible delay in payment given by the seller to the buyer affects SC profit more than the delay in payment availed by the buyer from the seller. However, the maximum profit is obtained when the permissible delay in payment is zero and delay payment that can be availed by the buyer from the seller is the maximum which is taken as buyer’s inventory cycle time in this study. The consolidated comparative statement of the effect of
different cases of ‘coordination’ and ‘no coordination’ under lost sale and backorder provides an overall idea about how one coordination mechanism performs compared to the other and ‘no coordination’.

The study of the performance of a four - level SC with ‘information sharing’ as coordination mechanism using Simulation software called ‘Supply Chain Role Play Game’ (SCRPG) revealed the following. The overall performance of SC is improved due to information sharing. The SD is seen to vary from 5.12 to 10% of the mean under back order and 8 to 14.5% (except for CDPP-19.1%) of the mean under lost sale. Detailed analysis shows that almost 80 to 90% of total cost values (except one or two out of ten just above or below the range) against all information sharing under both lost sale and backorder are within one standard deviation. The details mentioned above regarding SD with respect to mean and each cost values seem to be within the acceptable range since it is a manual simulation rather than computer based simulation. Due to the above reasons, with some caution, for all practical purposes the mean may be taken as performance measure. The improvement in overall performance compared to traditional case in the case of sharing demand and supply chain performance(D&SCP) is found to be 70% , and 36% in the case of sharing point of sales data per period (PSDPP, the case in which minimum improvement is obtained) compared to traditional case in the case of ‘lost sale’. In the case of backorder, it is 33% and 14% in the case of D&SCP and PSDPP respectively compared to ‘no coordination’. It is also found that the effect of information sharing is more effective in the case of lost sale compared to backorder. This phenomenon is due to the fact that lost sales cost decreases significantly in the case of D&SCP considering TDL under lost sales situation whereas back order cost does not decrease to that extent in the case of D&SCP considering TDL under backorder situation. The reduction in inventory cost for D&SCP compared to TDL is also more in the case of lost sale situation compared
to backorder situations. Overall analysis showed that “Demand and supply chain performance” (D&SCP) is ranked as the first in almost all cases except in the case of bullwhip effect (ranked as III) and lost sale cost (ranked as II). This indicates that overall performance of supply chain improves as information sharing contains more details. It is also to be noted that the difference between some pair of information sharing such as customer demand per period (CDPP) and customer demand history (CDH), Point of sales data per period (PSDPP) and point of sales data history (PSDH), Advance demand information (ADI) and forecasted demand information sharing (FDIS) is relatively less compared to other pairs. So, the difference in performance corresponding to these cases in each pair also found to be negligible. However, ADI is slightly better than FDI in almost all cases except in the case of bullwhip effect and inventory cost. CDH also performs slightly better than CDPP in most cases. This is due to the reason that lack of recording the demand data by the players in the case of CDPP. The scenario and reason remains same when compare PSDPP and PSDH which is slightly better compared to the other in most cases. It is found that under lost sales situation, the SC fill rate is obtained as nearly ‘one’ in all the cases of information sharing. In the case of back order situation, fill rate need not be considered as a performance measure as it will be always one (100%) as there is a provision of backorder for any shortage in each period. As far as bullwhip effect is concerned, it is not reduced with information sharing under both lost sale situation and backorder situation. Another unexpected finding in this study was that bullwhip effect is not reduced in the case of D&SCP in which best overall performance (minimum cost) is obtained and bullwhip effect is found to be minimum in the traditional case in which least overall performance (maximum cost) is obtained. The in-depth analysis in this study showed that the last upstream player (manufacturer in this case) might have taken over precautions in placing the ordered quantity to avoid inventory cost or lost sale
cost/ backorder cost. The bullwhip effect need not occur always due to lack of information sharing but also due to the incorrect ordering pattern of the last upstream player even with small variation in customer demand at retailer stage. So, it can be concluded that the lack of information sharing either produces bullwhip effect causing large inventory cost or backorder cost/lost sales cost for the extreme last player depending upon the approach of them.

The ‘t test’ proved that the difference found between the overall performance corresponding to a pair of information sharing is statistically significant.

6.4 Conclusion

The study on the performance of three-level SC using mathematical modelling and network SC using simulation modelling with price discounts and delay in payments as coordination mechanism revealed that the SC performance is significantly improved due to combination of mechanisms compared to individual cases as well as no coordination. So, combination of mechanisms can be tried to improve the SC performance considering all practical aspects. Sensitivity analysis in both the studies revealed that retailer has major role as it decides the order quantity of other players in the operating environment we have considered for our study. It is also found that the state (rate of return) of middle player affects more on SC profit. In the case of mathematical modelling and analysis, it revealed that SC profit becomes the maximum in the case where the delay in payment period availed by the buyer from the seller exceeds the buyer’s inventory cycle time. The rate of improvement in performance in the case of a combination of coordination mechanisms studied in comparing with the case of ‘price discount’ alone was found to be decreasing with an increase in price elasticity of demand.
Simulation modelling with price discount and delay in payment under lost sale and backorder revealed that the combination of these mechanisms are more effective in the case of lost sale compared to the other. Sensitivity analysis of this part of the study also shows the delay in payment between manufacturer and wholesaler affects more than the delay in payment between wholesaler and retailer. It is also noted that the increase in permissible delay in payment given by the up steam players and the decrease in delay in payment availed by the downstream players reduces the SC profit and maximum profit is obtained when the permissible delay in payment availed by the downstream payers is equal to the buyer’s inventory cycle time (maximum delay in payment permitted in this study considering the practice in industry) and the delay in payment given by the upstream players is equal to zero. The comparative statement of increase in profit with each other will help the practitioners to take appropriate decisions considering the effort required and other practical aspects of implementing the same.

In this study, overall sensitivity analysis revealed that order cost of retailer, rate of return of retailer & wholesaler, permissible delay in payment given by the manufacturer to the wholesaler, price elasticity of demand and the business case in which the system works (lost sale or backorder) play a major role in SC profit. These being specific cases, the numerical results obtained are not directly applicable to other cases. However, the general trends and more so, the methodology followed for the sensitivity analysis, may be used to gain insights regarding the effect of changes in decision variables on SC profit.

The experimental study conducted to analyze the performance of a four stage serial SC system with different types of information sharing using simulation game with live players concluded that the overall performance can be improved by sharing more details of operating parameters of each player
with other players. Analysis revealed that information sharing enhances the overall performance of the SC and the extent of improvement in performance depends on the type of information shared among SC members. In this study, the best performance is obtained with sharing of demand and SC performance (D&SCP) with all players and the least performance is with traditional case where only orders are being communicated. While concluding it is also to be noted that the unusual phenomenon of huge bullwhip effect happened in the case of information sharing where relatively best overall performance is obtained in this study. The reason we have found out for this incident is that large variation in ordering pattern of top upstream player without considering the small variation in end customer demand.

Ranking of different types of information sharing based on the various performance measures helped to understand its performance under various cases. Statistical test conducted in this part of the study provided a scientific support for the same. The rate of improvement in the overall SC performance corresponding to each type of information sharing with respect to traditional case is found out as significantly high in the case of lost sales situation compared to backorder situation. It shows that information sharing is more effective in the case of lost sales. Further to this, an element of human psychological effect was also involved in this study as students acted the role of each player which makes the study more realistic. So, it is expected that the results from this simulation study are more realistic to an extent, making the findings practically useful.

6.5 Scope for Future Work

The studies conducted as part of this research work can be straightaway extended to more realistic SC’s consisting of more number of levels and more players at each level with dynamic operating conditions. In this study, only two
categories of mechanisms (supply chain contracts and information sharing) are used to coordinate the SC, thereby to improve the performance. There are a number of coordination mechanisms other than price discounts and delay in payments (supply chain contracts) and information sharing cases used in this study. Some of the other mechanisms found in the literature under supply chain contracts are buyback, revenue sharing, and quantity flexibility contracts, etc. Under information sharing, mechanisms such as sharing of production schedule, cost sharing, sharing of marketing campaigning and advertisement programs, etc. are included. Apart from these, Information Technology (IT) and joint decision making are other categories of mechanisms available in the literature which can also be used to coordinate the SC and to analyze the improvement in performance. Under Information Technology, effect of use of Electronic Data Interchange (EDI), B2B e-Commerce etc may be studied. Joint decision making on replenishment, forecasting, ordering, cost aspects, etc. are some of the mechanisms under this category. Joint decision making on ordering quantity was also used along with price discount and delay payment in the simulation modelling of our study. All the mechanisms mentioned above can be used individually and jointly to analyse their effect on SC performance and such a study will be certainly relevant and useful to the SC practitioners.

In addition to the above, we have used only the case of a single product throughout our study. So, this study can be extended to a case of multiproduct. As far as operational parameters are concerned, fuzziness, capacity constraints, etc. can also be incorporated in the future study. In the present competitive and dynamic business environment, the concept of an agile supply chain is very important. So, the aspect of agility in an SC can also be made part of the scope for future work. It is certain that studies incorporating all these factors mentioned above will make further realistic in all aspects.
Sourcing, logistics, disruptions and effective use of IT are not considered in this study and these are some of the other important areas need to be addressed further to make the study completely helpful for the SC practicing community. As all these areas are vast and highly relevant, each one can be separately studied to solve the related issues to make a successful SC.

The mechanisms or issues we have so far discussed are quantitative in nature. Qualitative issues or mechanisms, such as behaviour, trust, ethics and satisfaction among players and customers are also very important for the long term success of SCM and to effectively implement the above mentioned mechanisms.

A detailed study of simulation modelling and analysis for various SC coordination issues under dynamic operating conditions using different categories of mechanisms and quantifying the value of the same will be helpful for the SC practitioners to select and implement the appropriate mechanism properly for a successful Supply Chain Management of a particular case. Performance measures other than Profit/Cost could also be used to broaden the study.

..........End..........