International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 9 (2015) pp. 21683-21698
© Research India Publications
http://www.ripublication.com

Measurement of Supply Chain Conflicts: a Petri Net Approach

Franklin R. John and Dr. R. Jayachitra

Associate ProfessorSchool of Engineering
Cochin University of Science and TechnologyCochin 682 022, INDIA
Mob: +91 9496978546
Corresponding Author: Franklin R. JohnE-mail: frankcusat@gmail.com
Assistant ProfessorDepartment of Mechanical Engineering
PSG College of TechnologyCoimbatore 641 004, INDIA
Mob: +91 9843349195Email: jayachitra_cbe@yahoo.co.in

ABSTRACT

Supply chains are generally complex and are characterized by numerous activities spread across multiple functions and organizations, which pose interesting challenges for effective supply chain coordination. Coordinating and managing distributed entities in a supply chain is a challenging task owing to conflicts present in such systems.This paper intends to provide an approach by means of the development of a Colored Petri Net (CPN)model to detect and analyze conflicts in an integrated supply chain system. It describes the analysis of various supply chain conflicts using *CPN Tools*, which is a tool for editing, simulation, state space analysis, and performance analysis of CPN models.The impact of conflicts present in the system is analyzed by simulating the CPN model. The simulation results show that there is substantial conflict between the suppliers and manufacturer, vendors and manufacturer and the customer and manufacturer. The conflicts between various elements are evaluated quantitatively. The methodology offers the user the ability to investigate the potential for conflicts in the system and manage the system to avoid such conflicts before they occur. This would also enable the supply chain to put sufficient protection (e.g. buffers) in strategic locations to handle the conflicts when it occurs.

Keywords: Supply chain management, Petri nets, Conflicts, Distribution channel.

1. INTRODUCTION

The management of a highly interconnected organization is an ever-increasing challenge in today's competitive business environment. Higher levels of uncertainty insupply and demand, shorter technology and product life cycles, the globalization, and the increased use of outsourcingresultin a complex international supply chain networks. As the level of complexity increasesandinterdependency becomes more prevalent, amplified levels of risk occur (Christopher, 1992). Various studies have adopted a variety of approaches/techniques to investigate these complex issues. A wide range of topics, including riskmanagement (Finch, 2004), operational strategies (Croxton et al., 2001), proactivemanagement (Sinha, Whitman andMalzahn, 2004), and supply chain design (Lowson, 2002) have all contributed to the understanding of how to manage today'scomplex and interdependent organizations.

Coordinating and managing distributed entities in a supply chain is a challenging task owing to conflicts present in such systems. Conflict is defined as the behaviors of interdependent parties in response to potential or actual obstructions that impede one or more of the parties achieving their goals (Gaski, 1984). Conflict occurs in situations where two or more interdependent parties (either individuals or groups) have interests, outcomes, and/or goals that are incompatible in some way. Conflict can occur in both cooperative and competitive contexts, as well as in mixed motive contexts that are marked by a combination of competitive and cooperative features.

The need for conflict identification is well documented.For example, Rosenburg and Stern (1970)observedthat "within any system or network: the interdependence among components of the system is highlighted since two or more units must take each otherinto account if they are to accomplish their respectivegoals". More recently, supply chain conflictshave garnered an increased attention from supply chainmanagers due to the potentially detrimental impactthey can have on performance of supply chains. A single disruptioncaused by a conflict can halt the flow of material in thesupply chain impacting not only the tier of the supplychain where the disruption occurs but all the way to theend customer. Hendricks and Singhal(2005)showed that the impact of these disruptions canaffectshareholders'wealth (publicly announced disruptionswere shown to decrease wealth by 10%inthe short term and 40% over the long term) and supply chain operational performance (disruptions in publiclytraded firms, on average, associated with a 107% drop in operating income, a 114% dropin return on sales and a 93% drop in return on assets). John and Prasad (2012a) reviewedvarious perspectives on supply chain conflicts and reported gaps existing in the current literature.

Ideally, supply chain partners could discover potentialconflicts before they occur and work together to resolvethe issue and redesign the supply chain to avoidfuture conflicts (John and Prasad, 2012b). While this ability to discover and preemptconflict would be a valuable asset to the managementand design of supply chains, there arelimitedattemptsfound in the literature on how to accomplish this.

This paper intends to provide an approach by means of the development of a ColouredPetri Net (CPN)model to detect and analyze conflicts in an integrated supply chain system. It describes the analysis of various supply chain conflicts using *CPN Tools* (Jensen and Kristensen, 2009), which is a tool for editing, simulation, state space analysis, and performance analysis of CPN models.The use of Petri Nets allows fora high-level customizable interface for the supply chain manager. The methodology adopted by Chen and Hall (2007) is used here to evaluate conflicts between various elements in the supply chain.

The paper is structured as follows: the background and related literature is outlined in the next section, followed by a brief introduction about the Colored Petri Nets. The application of the tool is demonstrated on a supply chain for the manufacture and sale of textile machine spare parts. The supply chain is modeled and analyzed by *CPN Tools* and conflicts between the suppliers, manufacturer, vendors and the customer are then evaluated. Lastly, the findings are concluded and the future research directions are outlined.

2. BACKGROUND AND THE RELATED WORK

Existing literature on supply chain modeling can be classified into three categories: mathematical modeling, simulation based modeling, and network based modeling (Zhang, Lu and Wu, 2011). Mathematical models include linear programming, integer/mixed integer programming, non-linear programming and stochastic programming. The challenges with mathematical programming lie in the size and complexity of the problems. Supply chain problems introduce a large number of variables and constraints which is inordinately difficult to maintain and requires computational burden. In addition, convergence of the mathematical models, especially non-linear programming problems have long been recognized as a critical issue. Thus research on exploring the use of simulation in SCM modeling and analysis attracts greater attention. Kleijnen and Smits (2003) provide a comprehensive survey of different simulation applications in SCM. Jain et al. (2001) conducted a simulation study on large scale logistics operations in a supply network and concluded that simulation helps in improving the forecast accuracy leading to significant cost savings. Another emerging supply chain modeling tool is Petri Nets which has a well-defined mathematical foundation and an easy-to-understand graphical feature. Based on a strong mathematical formalism, Petri Nets can setup mathematical models to describe the behavior of the system. The graphical nature makes it a self-documenting and powerful design tool to facilitate visual communication between the people who are engaged in the design process. If necessary, Petri Nets can be extended to conduct simulation based analysis. It has been widely studied and successfully applied in different discrete event dynamic systems and the application to SCM has attracted growing interests from both academia and industrial practices.

As a complex and distributed system, SC needs to combine entities into a synthesized system or to outsource some parts of production. These strategies increase the vulnerabilities of the firms in an uncertain environment, which results in operational risks. The disruptions can include a wide variety of events such as transportation delays, port stoppages, accidents and natural disasters, poor communication, quality and operational issues. Wu and Blackhurst(2004) proposed to synthesize supply chain entities into an integrated system and then analyze disruptions in the integrated supply chain. Further, Wu et al. (2007) studied the use of Petri Net to determine how changes or disruptions propagate in supply chains and the influence of those changes or disruptions on the supply chain system. Blackhurst et al. (2008) presented a methodology based on extended Petri Nets to discover supply chain conflicts which cause detrimental effects to system performance.

Elmahi et al. (2002) proposed a Petri Net model based on *Max PlusAlgebra*to control supply chains. Landeghem and Bobeanu(2002) presented a method for modeling supply chains by using Petri Nets and the same is demonstrated through the Beer Game. Liu et al. (2007) developed a similar approach for modeling the relationships in supply chains. Makajic-Nikolic et al. (2004) used Colored Petri Nets to study the performance of a series supply chain by means of *CPN Tools*. A CPN model has been constructed to study the bullwhip effect in decentralized supply chains where individual nodes use aggressive ordering based on deterministic customer demand patterns. GehlotandNigro(2012) described the use of Colored Petri Nets in the simulation and analysis of re-entrant manufacturing systems with inspections.

3. COLORED PETRI NETS AND CPN TOOLS

Colored Petri Nets combine the graphical components of ordinary Petri Nets with the strengths of a high level programming language. The basic components of Petri Nets are places, transitions, and arcs. Places are displayed pictorially as circles (or ovals) and can be used to represent states, while transitions are displayed as rectangles and can be used to represent events. Arcs connect a place to a transition or a transition to a place, but they do not connect two places or two transitions.Arcs from a place to a transition may be labeled by weights which can specify simple pre-conditions for the firing of a transition. Petri Nets provide a frameworkfor modeling a variety of systems, including distributed and concurrent systems with both synchronous and asynchronous communication. Colored Petri Nets extend the vocabulary of ordinary Petri Nets and add features that make them suitable for modeling large systems. While Petri Nets provide the framework for process interaction, CPNs add a high level inscription language,which allows for the definition of data types (bothsimple and complex), the creation of functions of arbitrary complexity, and the manipulations of data values. Therefore, in a CPN model, tokens can be coded as data types with a rich set of values (called color sets) and arc inscriptions can be computed expressions, not just constants.

CPN models can be constructed using *CPN Tools*, a graphical software tool used to create, edit, simulate, and analyzemodels. *CPN Tools* has a graphical editor that allows the userto manipulate the various Petri Net components. One of the key advantages of *CPN Tools* is that it visually divides thehierarchical components of a CPN, enhancing its readabilitywithout affecting the execution of the model. In addition,*CPN Tools* allows for the creation of fusion sets, which allowfor an instance of the same place to occur multiple timeswithin the model to enhance readability. *CPN Tools* also providesa monitoring facility to collect data from simulationsand conduct performance analysis of a system. Unlike traditionaldiscrete event systems, CPNs allow for state spacebased exploration and analysis, which is complementary topure simulation based analysis. State space analysis canbeused to detect system properties such as the absence of deadlocks.

4. CASE STUDY

The application of the tool is demonstrated on the supply chain for the manufacture and sale of textile machinery parts. The system consists of two suppliers, manufacturer, vendors and the customer.

The specific series of processes involved in the manufacturing of this particular part of textile machinery are the following. Raw materials (MS ground bars) are ordered from two suppliers - the selection of the supplier depends on the inventory available, freight charges and the possible lead times. Upon arrival of the parts at the manufacturing facility, the bars are cut to specified length and chamfered on one of its ends. Mechanical operations like turning and thread rolling are outsourced. Finally, the parts are zinc plated at an outside vendor. 100% inspection is carried out after each operation.

It is the manufacturer's responsibility to ensure that the complete production process of the textile machinery parts continuously complies with the customer requirements. The manufacturer shall, therefore, exercise adequate control (by inspection) over all the subcontractors and vendors preparing the machine parts. The method of inspection adopted by the manufacturer will obviously depend on local circumstances and the type of product being manufactured. Special attention shall be paid to those operations (like CNC turning, thread rolling, zinc plating etc.), to avoid process rejection that will result in the scrapping of the whole value added part. It is observed that up to 50% rejection happensafter the final zinc plating process. However, 98% salvaging of rejected parts are possible through re-working.

In this paper, the issues of conflict between the outside vendors and the manufacturer arise from the requirement that all machining operations required for this part must be completed before the shipment of the final product to the customer. Therefore, the performance of the manufacturer depends on material suppliers and all outside vendors to deliver the raw material and parts on time, after performing various operations and thus on decisions made by the vendors, who are concerned about their own costs. Various causes of conflicts that can be analyzed in the supply chain are (1) scarcity of right quality material, (2) the non-availability of parts at a specified time from the vendors and (3) the rejection of finished parts after inspection. The company experienced issues with material suppliers (however this was resolved by choosing the appropriate supplier and advance procurement planning) of raw material as well as the outside vendors who perform various precise machining operations.

4.1 CPN MODEL

The CPN model of the supply chain is described in this section. The overall system is depicted in Fig. 1. Fig. 1(a) models thesuppliers and the manufacturer.

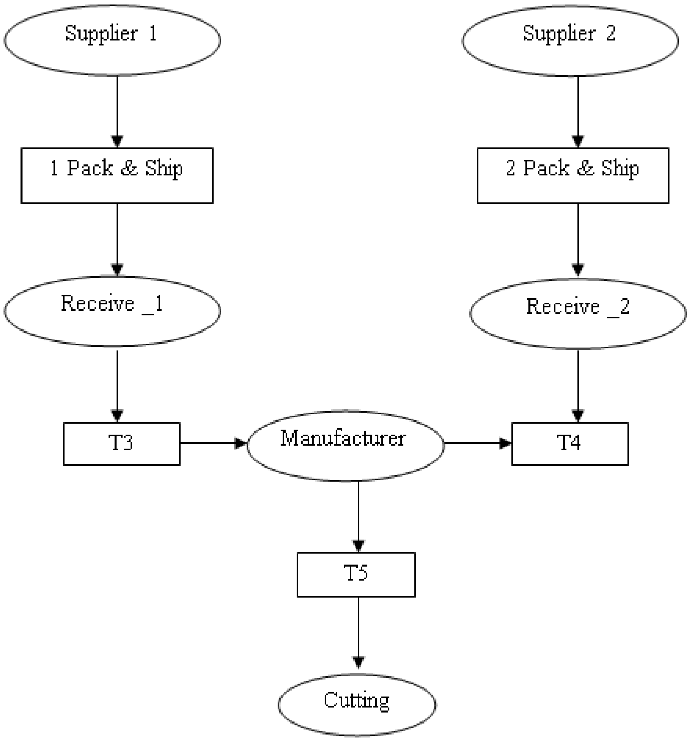

Fig 1(a)CPN Tools: Supplier and the manufacturer

Fig. 1(b) models the CNC turning (outsourced) and the quality inspection, Fig. 1(c) models length correction, thread rolling, grinding, squeezing and the zinc plating (outsourced). The place representing the manufacturer (Fig.1a) denotes an OR operation whichallows single entities to be combined into an integrated system allowing the choice of operations from each system to be performed based upon predetermined conditions. This operator allows the manufacturer to select between the two suppliers for the delivery of raw materials. Transitions T12, T16 and T21 represent the inspection procedures after CNC turning, thread rolling and the zinc plating.

4.2 MEASUREMENTS OF CONFLICTS

Chen and Hall (2007) studied the extent to which an optimal schedule for the manufacturer's problem can be sub-optimal for the suppliers' problem and vise versa. Let ν and γ denote an optimal schedule for the suppliers' problem $\sum_{i=1}^{s} Fi$ (i.e., the suppliers act jointly to minimize the total performance measure $\sum_{i=1}^{s} Fi$) and for the manufacturer's problem G (i.e., the manufacturer acts alone to minimize a performance measure G) respectively. Conflicts between the suppliers and the manufacturer are measured by the following relative errors between ν and γ:

(i) $\left[\sum_i Fi(\gamma) - \sum_i Fi(\nu)\right] / \sum_i Fi(\nu)$ and

(ii) $[G(\nu) - G(\gamma)] / G(\gamma)$

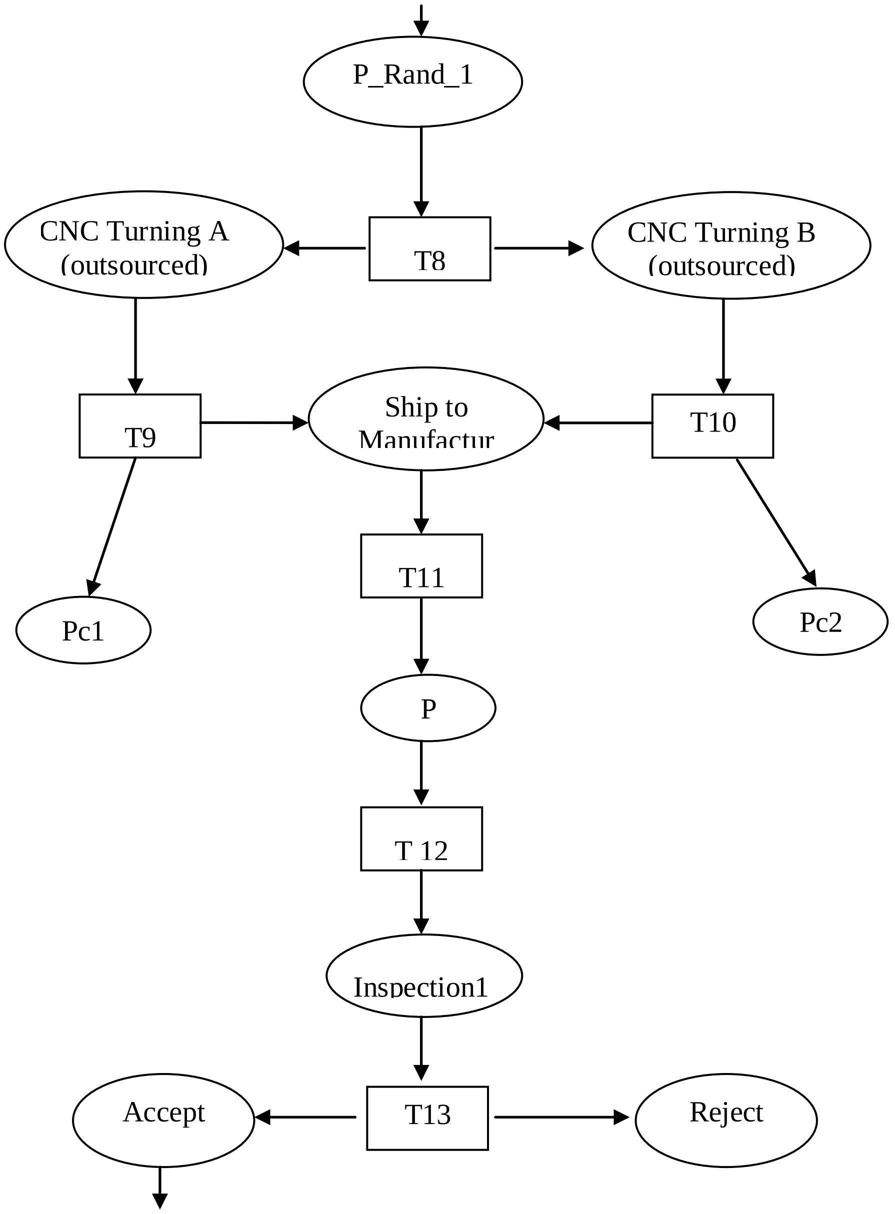

Fig 1 (b) CPN *tools*: chamfering, turning and inspection

where (i) represents the relative error of the optimal schedule for the manufacturer's problem when used for the suppliers' problem, and (ii) represents the relative error of theoptimal schedule for the supplier's problem when used forthe manufacturer's problem. How these conflicts are resolved depends on the relative bargaining power of the suppliers and the manufacturer, and cooperation mechanisms that achieve this resolution need to be developed. It also describes the choice of cost functions for the suppliers and the manufacturer. Because the suppliers do not deal directly with

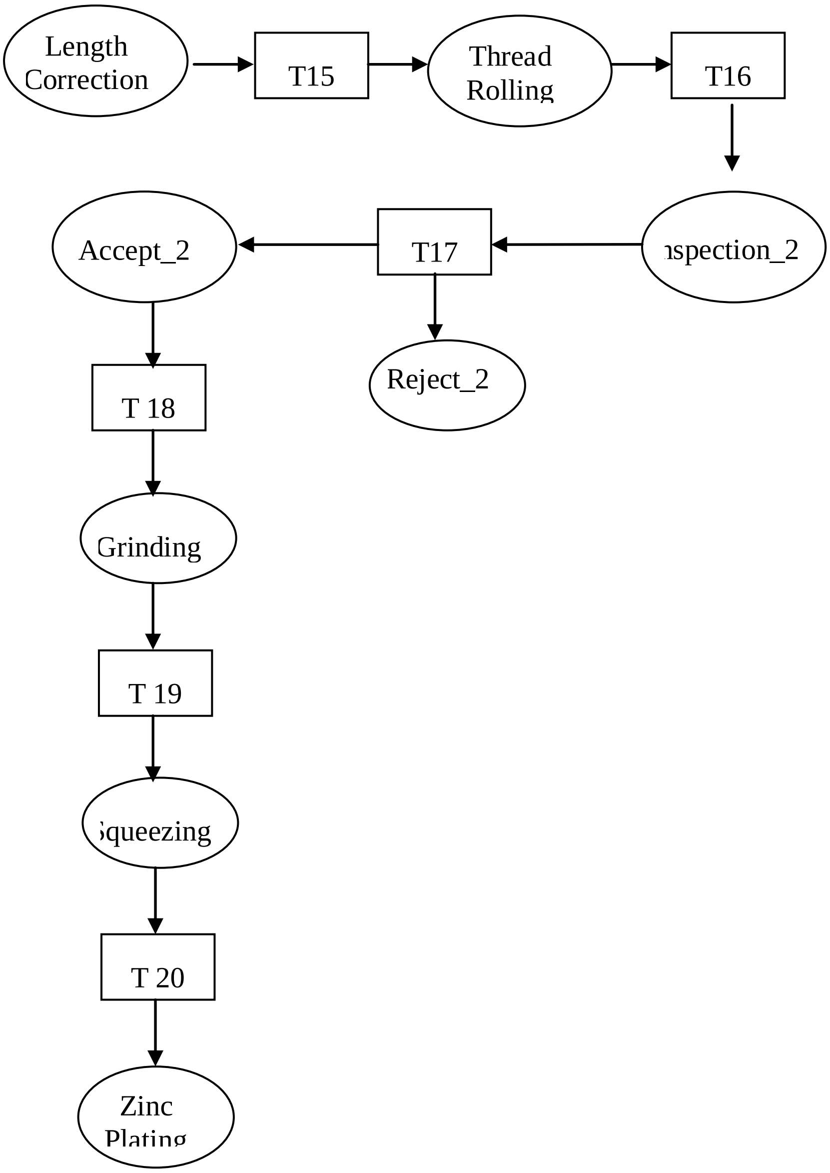

Fig 1 (c) *CPN tools*: rolling, grinding, squeezing and plating

customers, their objective is internally focussed; therefore, the minimization of work-in-process cost is considered. Furthermore, minimizing the total completion time of the jobs in a plant is equivalent to minimizing the average number of jobs in the plant and hence minimizing the congestion of the plant (Hopp and Spearman, 2000). For the manufacturer, however, customer service is important; therefore, total lead time and maximum lateness are used as cost measures. Total lead time measures average customer service, whereas maximum lateness measures worst case customer service.

Therefore, using total completion times, conflicts between the suppliers and the manufacturer are measured as:

$$\left[\sum_{j\epsilon N} Cj(\nu) - \sum_{j\epsilon N} Cj(\gamma)\right] / \sum_{j\epsilon N} Cj(\gamma)$$

Where

$\sum_{j\epsilon N} Cj(\nu)$ = total completion time of the jobs at the manufacturer in schedule ν
$\sum_{j\epsilon N} Cj(\gamma)$= total completion time of the jobs at the manufacturer in schedule ϒ
i = 1,…..,s ; j = 1,…….,n and
N = $\{1, \ldots., n\}$ where n is the number of jobs

Also $Cj(\nu)$ = $\max_{1\leq i \leq s}\{Cij(\nu)\}$ where $C_{ij}(\nu)$ is the time at which parts for job j aredelivered from supplier S_i to the manufacturer.

4.2.1 CONFLICTS BETWEEN SUPPLIERS AND MANUFACTURER

The performance of the manufacturer depends on the last supplier to deliver a part for each job, and thus on decisions made by all the suppliers. However, the suppliers are concerned about their own costs which are not, in general, optimised by the same sceduling decisions that optimize the manufacturer's cost. For the distribution channel, for random values of time (in days), $Cj(\nu)$,$Cj(\gamma)$ and the relative errors are given the Table 1 (assuming

Time (days)	***Cj(v)***	***Cj(γ)***	**Relative error (%)**
22	22	22	0
46	24	22	9.09
69	23	22	4.54
96	27	22	22.73
123	27	22	22.73
149	26	22	18.18
175	26	22	18.18
198	23	22	4.54
226	28	22	27.27
252	26	22	18.18
281	29	22	31.82
305	24	22	9.09
328	23	22	4.54
349	21	22	0
376	27	22	22.73
400	24	22	9.09
428	28	22	27.27
452	24	22	9.09
476	24	22	9.09

498	22	22	0
523	25	22	13.64
548	25	22	13.64
574	26	22	18.18
595	21	22	0

Table 1 Relative errors between the schedules of supplier and manufacturer

that the manufacturer expects the raw materials supply in 22 days). For a small number of randomly generated time, $Cj(v)<Cj(\gamma)$. For these cases, we record the relative error as zero because the actual relative error between v and γ is always non-negative. Because the relative error (among the non-zero values) is at least 4.54%, it is concluded that there is substantial conflict between the suppliers and manufacturer.

4.2.2 CONFLICTS IN OUTSOURCING

It was observed that when the manufacturing company outsouce some of its production operations to other contract manufacturers, the manufacturing costs are often lower and also, since the vendor provides shared service, the manufacturer need not pay for under-utilized capacity, which lowers the inventoty carrying costs. Since the contract manufacturer has more production capacity (the ability to produce more goods) than the original manufacturing company, it can respond to increased production requirements faster than the original manufacturer. Instead of the original manufacturer making a capital investment in new equipment to increase its production capacity, it informs the contract manufacturer that it requires more goods. Although the requested increase (or decrease) in production might change the terms and costs associated with the production contract, it is more flexible than making a one-time capital investment that could be idle if the increased demand diminishes.

Despite outsourcing has many potential advantages, it leads to several problems and risks at the same time. Outsourcing the production procecces also faces risks, such as the legal disputes, increasing dependence with vendors, disclosure of commercial secrets, andconflicts with outsourcing partners. The uncertanties in the component supply from vendors causes disruptions in the supply chain which results in failure in delivering final product to the customer. Simulation analysis is, therefore, performed on the CPN model of the supply chain to measure the risk of conflicts resulted from such disruptions. The relative errors between the schedules of the vendors and manufacturer are calculated from the simulation results and presented in table 2. The number of component parts rejected by the manufacturer, after inspection (inspection station 1), is given in table 3.

Time (days)	**$Cj(v)$**	**$Cj(\gamma)$**	**Relative error (%)**
26	26	24	8.33
50	24	24	0
73	23	24	0
100	27	24	12.50

127	27	24	12.50
153	26	24	8.33
179	24	24	0
202	25	24	4.17
230	28	24	16.67
256	26	24	8.33
285	29	24	20.83
309	24	24	0
332	23	24	0
353	21	24	0
380	27	24	12.50
404	24	24	0
432	28	24	16.67
456	24	24	0
480	24	24	0
502	22	24	0
527	25	24	4.17
552	25	24	4.17
578	26	24	8.33
599	21	24	0

Table 2 Relative errors between the schedules of vendor and manufacturer

Table 4 and table 5 show the number of parts rejected by at inspection stations 2 and 3 respectively.

Time (days)	***No of rejections***
28	28
52	23
75	23
102	23
129	25
155	29
181	25
204	21
232	23
258	24
287	33
311	27
334	34
355	34
382	28
406	30

434	40
458	26
482	40
504	26
529	24
554	39
580	27
601	23

Table 3 parts rejected at inspection station 1

Time (days)	***No of rejections***
30	28
54	19
77	31
104	32
131	27
157	29
183	20
206	29
234	21
260	41
289	38
313	20
336	27
357	28
384	22
408	25
436	29
460	33
484	28
506	30
531	29
556	25
582	30
603	25

Table 4 parts rejected at inspection station 2

Time (days)	***No of rejections***
33	15
57	11
80	18
107	9

134	16
160	16
186	16
209	12
237	12
263	14
292	15
316	10
339	14
360	8
387	11
411	18
439	15
463	15
487	11
509	16
534	14
559	12
585	10
606	12

Table 5 parts rejected at inspection station 3

4.2.3 CONFLICTS BETWEEN MANUFACTURER AND CUSTOMER

Relationships between buyers and sellers, in the context of business-to-business purchasing and supply chian management practices, are often strained due to differences in expectations or actual performance related to pricing.The primary source of conflict between buyers and sellers is generally rooted in the buyer's desire to rapidly improve its financial performance at the expense of other key stakeholders, namely suppliers. Conflicts between buyers and sellers result in wasteful disagreements, quality and delivery problems, re-work and loss of focus on end customer needs (Emiliani, 2003).

Time (days)	*Cj(v)*	*Cj(γ)*	Relative error (%)
64	22	25	0
88	24	25	0
111	23	25	0
138	27	25	8
165	27	25	8
191	26	25	4
217	26	25	4
240	23	25	0
268	28	25	12

294	26	25	4
323	27	25	8
347	24	25	0
370	23	25	0
391	21	25	0
418	27	25	8
442	24	25	0
470	28	25	12
494	24	25	0
518	24	25	0
540	22	25	0
565	25	25	0
590	25	25	0
616	26	25	4

Table 6 Relative errors between the schedules of customer and manufacturer

The CPN model is used for various experiments to study the system behavior and particularly, the impact of conflicts in the supply chain. For random time durations of delivery of finished spare parts to the customer, table 6 shows the relative errors between the schedules of manufacturer and the customer.It is observed that the major reasons for conflicts (shown by variations in quantity delivered) are the parts rejected at various inspection stages in the supply chain, as given in tables 3 – 5.

5. CONCLUDING REMARKS

An approach to the simulation and analysis of a supply chain system using Colored Petri Nets is described in this paper. The impact of conflicts present in the system is analyzed by simulating the CPN model. The simulation results show that there is substantial conflict between the suppliers and manufacturer, vendors and manufacturer and the customer and manufacturer. The methodology offers the user the ability to investigate the potential for conflicts in the system and manage the system to avoid such conflicts before they occur. These conflicts stem from the fact that while each single entity in the supply chain may be working towards localized goals for its own operations, integrating the single entities into one system may lead to conflicts due to differing goals or lack of visibility of the goals of the supply chain as a whole. The tool would allow for possible conflicts to be discovered in the design phase. This would enable the supply chain to put sufficient protection (e.g., buffers) in strategic locations or contingency plans in place to handle the conflicts when it occurs.

This approach also allows the manufacturer to quantify the impact of conflicts for suitable precautionary measures to be adopted in the design phase.A variety of manufacturer’s problems were considered, where the delivery time of aproduct is the maximum of the suppliers’ delivery times for the parts needed for that product. It was shown that an optimalschedule for the manufacturer’s problem can be far from optimal for the suppliers’ problem,andvice versa.

However, supply chains are complex dynamic systems with intricate interrelations and cumbersome functions. Therefore, additional modeling work is required to capture all characteristics of conflicts in real supply chains. An important research topic is to implement various cooperation mechanisms in the chain to reduce conflicts. Studies that examine the benefits of cooperation should also consider the value of organizational integration. Another research issue is the optimization of the supply chain system by minimizing the effect of conflicts.

6. REFERENCES

1. Blackhurst, J.,Wu, T. and Craighead, C.W., 2008.A systematic approach for supply chain conflict detection with a hierarchical petri net extension.*Omega*, 36 (5),680-696.
2. Chen, Z.L. and Hall, N.G., 2007. Supply chain scheduling: Conflict and cooperation in assembly systems.*Operations Research*, 55 (6), 1072-1089.
3. Christopher, M., 1992.Logistics and supply chain management.*Pitman Publishing*, London.
4. Croxton, K. L., Garcia-Dastugue, S. J., Lambert, D. M. and Rogers, D. S., 2001.The supply chain management processes.*International Journal of LogisticsManagement*, 12 (2),13-36.
5. Emiliani, M.L., 2003. The inevitability of conflict between buyers and sellers.*Supply Chain Management: An International Journal,* 8 (2), 107-115.
6. Elmahi, I.,Grunder, O. andElmoudni, A., 2002. A petri net approach for the evaluation and command of a supply chain using the max plus algebra.*Proceedings of the Second IEEE International Conference on Systems, Man and Cybernetics,* 6-9 October 2002, Hammamet, Tunisia, Vol. 4.
7. Finch, P., 2004. Supply chain risk management.*Supply Chain Management: an International Journal,* Vol. 9 No. 2, pp. 183-196.
8. Gaski, J.F., 1984. The theory of power and conflict in channels of distribution.*Journalof Marketing*, Vol. 48, page 9.
9. Gehlot, V. and Nigro, C., 2012.Modeling and simulation of a re-entrant manufacturing system using colouredpetrinets.*Proceedings of the 45th Annual Simulation Symposium (ANSS '12), Society for Computer Simulation International*, San Diego, CA, USA, Article 6, 8 pages.
10. Hendricks K.andSinghal V., 2005.An empirical analysis of the effect ofsupply chain disruptions on long run stock price performanceand equity risk of the firm.*Production and OperationsManagement,*14 (1), 35–52.
11. Hopp, W. J. and Spearman, M.L., 2000.Factory Physics, 2nd ed.*Irwin McGraw-Hill,* New York.
12. Jain, S., Ervin, C., Workman, R.W. and Collins, L.M., 2001.Analyzing the supply chain for a large logistics operation using simulation.*Proceedings of*

the 2001 Winter Simulation Conference, 9-12 December 2001, Arlington, USA, 1123-1128.

13. Jensen, K. andKristensen, L.M., 2009.Colouredpetri nets – modelling and validation of concurrent systems.*Springer-Verlag*, Heidelberg, Berlin.
14. John, F.R. and Prasad, P.S.S., 2012a. An overview of conflicts in supply chain systems.*International Journal of Logistics Systems and Management,* 11 (3), 325-353.
15. John, F.R. and Prasad, P.S.S. 2012b. Supply chain conflict detection with coloured petri nets.*Journal of Advances in Management Research*, 9 (2), 208-216.
16. Kleijnen, J.P.C. and Smits, M.T. 2003. Performance metrics in supply chain management. *The Journal of the Operational Research Society,*54 (5),507-514.
17. Landegehm, R.V. and Bobeanu, C.V., 2002. Formal modeling of supply chain: an incremental approach using petri nets.*Proceedings of 14th SCS Europe BVBA*, 23-26 October 2002, Dresden, Germany.
18. Lowson, R., 2002. The implementation and impact of operations strategies in fast-moving supply systems.*Supply Chain Management: An International Journal,* 7 (3), 146.
19. Makajic-Nikolic, D., Panic, B.andVujosevic, M., 2004. Bullwhip effect and supply chain modeling and analysis usingCPNTools.*Proceedings of the Fifth Workshop and Tutorial on Practical use of Coloured Petri Nets and CPN Tools,* 8-11 October 2004, Aarhus, Denmark.
20. Rosenberg, J. Larry and Stern L.W., 1970.Towards the Analysis of Conflicts in Distribution Channels: A Descriptive Model. *Journal of Marketing,* 34(4), 40.
21. Sinha, P. R., Whitman, L. E., and Malzahn, D., 2004. Methodology to mitigate supplier risk in an aerospace supply chain. Supply *Chain Management: An International Journal,* 9 (2), 154-168.
22. Wu, T. and Blackhurst, J., 2004.Modeling methodology for supply chain synthesis and disruption analysis.*Proceedings of SPIE, Vol. 5605 – Intelligent Systems in Design and Manufacturing,* 25 October 2004, Philadelphia, pp. 25-35.
23. Wu,T., Blackhurst, J. and O’Grady, P., 2007. Methodology for supply chain disruption analysis, *International Journal of Production Research*, 45 (7), 1665-1682.
24. Zhang, X., Lu, Q. and Wu, T., 2011.Petri Net based applications for supply chain management: an overview, *International Journal of Production Research,* 49 (13), 3939-3961.