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Multi-objective optimization for preemptive and predictive supply chain operation

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Article Info	ABSTRACT
	At present, the manufacturing industry has undergone a tremendous change in its operating principle with respect to the supply chain management system where the demands of consumers are dynamically and exponentially rising. Although Industry 4.0 offers a significant solution to this principle with the aid of its predictive automated operating process, till date there is less number of fault tolerant model that can effectively meet the standard demands of supply chain planning. Therefore, the proposed system introduces an analytical model where predictive optimization is carried out towards bridging the gap between supply and demands in supply chain 4.0. An analytical framework is a design from constraints derived from practical environment in order to offer better applicability of it. The study outcome shows that the proposed model could offer better performance in comparison to the existing optimization method with respect to the better budget control system for offering predictive and preemptive model design. *Copyright © 2020 Institute of Advanced Engineering and Science.* *All rights reserved.*

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1. INTRODUCTION

Supply Chain Management offers a highly structured management mechanism that controls the flow of products right from raw material management to sales outlet [1]. There are many goals of supply chain management system that range from organizing and planning of products flow to enhance the baseline value of customer [2]. Without a supply chain management system, it is nearly impossible to streamline the business demands as per the demands of the customer for any products or services. However, there are various challenges associated with supply chain management system encountered by the Managers. The primary challenge is associated with various practical problems in servicing the customers, which are all about delivering the products/services just in time to customers. The second challenge is about controlling the operational cost factor owing to the involvement of various parameters, such as, labor, freight, fuel, technology, etc. The third challenge is associated with the presence of the uncertainty factor in the form of risk. Risk management is yet an open issue in the supply chain management system, as there are a large number of factors that control risk [3-5]. The fourth challenge is about establishing as well as managing the relationship between various suppliers effectively. Hence, controlling the supply chain management system is a complex proposition. Presently, the industry employs various tools such as, Lean Inventory Tools, Bid and Spend Tools, Shipping Status Tools: Alerts and Updates, Supply Chain Analytics and Reports, Warehouse Management, Demand Forecasting, Order Processing Tools, Collaboration Portals, Supplier Management and Specialized Freight Handling [6]. However, these tools are not sufficient to completely automate the entire process of supply chain operation. Hence, this challenge is targeted to be solved using an upcoming automated standard called as Industry 4.0 that deals with the exchange of

significant data concerning manufacturing technologies [7]. The successful implementation of Industry 4.0 can be carried out using various new technologies, such as, cognitive computing, cloud computing, internet-of-things, etc. [8]. It is expected that Industry 4.0 targets to introduce a smart manufacturing unit where a distributed system evolves to generate and process demands along with dispatching the demands. There are various benefits obtained by incorporating Industry 4.0 in supply chain management system, viz. i) enhanced productivity, ii) enhanced efficiency, iii) magnified scheme of sharing knowledge, iv) support for collaborative work environment, v) incorporation of agility and flexibility, vi) easier compliance, and vii) better experience of customers [9, 10]. Apart from this, Industry 4.0 is also anticipated to reduce the cost of operation. However, they all depend upon various attributes, such as, less number of quality based issues, optimal resource utilization, minimization of cumulative cost of operation, highly controlled waste management, etc. However, incorporation of Industry 4.0 in the various manufacturing field, e.g., the automotive industry is just a beginning, and there is a long way to go even to offer a standard solution. The proposed paper discusses one such framework where Industry 4.0 concept is framed up over automotive industry for an effective supply chain management system.

Supply Chain 4.0 is an upcoming standard which integrates a predictive supply chain management operation with the Industry 4.0 standard [11]. Industry 4.0 is more inclined towards incorporating automation compliance with the distributed and pervasive environment. Therefore, there is a scope for introducing higher degree of disruptive technologies by it [12, 13]. Owing to this, the conventional mechanism of supply chain management has been revolutionized, and it also gave rise to different technologies to support its working principle. This approach has also brought forward higher degree of adaptability to the supply chain management system for introducing significant operational benefits [14]. One of the biggest challenges that Supply Chain 4.0 is targeting is to keep a balance between dynamic customer demands with the offering of predictive supplies [15].

A closer look at the pictorial representation of Supply Chain 4.0 shown in Figure 1 shows that-in coming days, the machine, as well as the system, will perform the predictive operation in order to meet the problem associated with supply and demands. Apart from this, the automotive industry is one of the rising industries with massive ranges of dynamic customers, along with a heavy competitive range of automobile products [16]. In such cases, the components of the automobile are manufactured in automobile manufacturing units where the system generated machine is anticipated to offer feedback about the existing capacity of manufacturing. The manufactured automobile parts are then dispatched from manufacturing units to stocking plants where the system/machine computes the exact location of the specific stocking plants from a given list of stocking plants. It will mean that the machines are making all the decision to offer increased productivity [17]. The stocking plant is also anticipated to use robots and mechanical devices for stock management. Various wireless and mobile technologies are also anticipated to be used for this purpose within the stocking plants [18]. This operation is highly distributed in nature while different stocking plants also update with inventories of each other. The next process is system/machine based delivery of the manufactured automobile units as per the demands raised by the users over certain application that runs on the distributed interface of Supply Chain 4.0. Another significant target of Supply Chain 4.0 is to incorporate transparency [19, 20]. If the data and services are transparent, then it can offer exact information to the analytics that can also consider various internal and external attributes, e.g., weather, channel, promotion, prices, product, sales, etc. All this dynamic input contributes to instruct the automobile manufacturing units to make the necessary manufacturing of the automobile products. The idea is not only to offer proper management of supply chain in distributed order but also to increase the profit margin of all the parties involved in the supply chain management system.

At present, various studies have been carried out in existing system towards re-framing supply chain management system in the viewpoint of automation. The significance of using *cloud ecosystem* over enhancing supply chain operation was discussed by Leukel et al. [21]. Such implementation could further enhance if analytical-based modelling are carried out. Srivathsan and Kamath [22] have presented such an approach using *sequential solution*. More improvement could be offered if the cloud-based model could be integrated with the logical-based concept for better resiliency. Pavlov et al. [23] have used jointly probabilistic modelling and *fuzzy logic* to evaluate the effectiveness of the resiliency factor of supply chain model. Literature has also witnessed the usage of evolutionary-based approach towards cost assessment modelling of supply chains. Wang et al. [24] have used a *genetic algorithm* for cost management when the supply chain is integrated with more advanced device-to-device communication. Most recently, a unique work carried out by Choi [25] has used *system theory* for modelling supply chain model considering the complexities associated with big data too. The work carried out by Yue and Chen [26] has addressed the problem connected with resource allocation while working on the supply chain. The authors have introduced optimization principle using fuzzy logic for facilitating better decision operation when supply chain is associated with internet-of-things. However, there are also evidences that the usage of typical

mathematical approach assists in modelling supply chain operations. The work of Nishi et al. [27] has used the Lagrangian method in order to optimize the planning process in the supply chain without many dependencies on data. Mathematical modelling has also been found to use agent-based approach for better scheduling of projects in the supply chain as seen in the work of Lau et al.[28]. The study is more inclined towards an effective scheduling process without much focus on transparency in complete scheduling process. The significance of data and process transparency and its discussion has been initiated by Groth [29]. Most recently, the security concerns associated with supply chain operation being a distributed nature has attracted attention of researchers. Fu, and Zhu [30] have used the blockchain-based operation to secure the operation involved in large scale supply chain process. Adoption of multiple agents for rectifying the distributed process involved in the supply chain was discussed by Kumar and Mishra [31]. The model has assisted in generating the best possible plan to carry out the execution process of the supply chain. Usage of *adaptive strategy* towards supply chain management system has been carried out by Gaudreault et al. [32]. The study implements search-based tactics in order to assist in better coordination system over the distributed operation of the supply chain. A unique study carried out long back by Chan and Chan [33] has shown that the ambiguity factor connected with demand can be mitigated if the approach towards considering contract to be completed is considered. Ulieru and Cobzaru [34] have taken a specific case study to build supply chain operation using the *Holonic enterprise*. Another optimization scheme has been introduced by Xin [35] where a retail industry has been considered, and a web-based service has been designed for better planning management. Zheng and Cao [36] have investigated specific aspects of supply chain management, considering the food industry. Xu et al. [37] have used *ensemble-based strategy* for optimizing the migration strategy involved in a supply chain management system. Wenzhou et al. [38] have studied the cost factor involved in enterprise application in supply chain operation. Involvement of the human factor also has an impact on supply chain management. This fact is considered in the study of Dani et al. [39] and Hongxia [40]. Therefore, there have been various studies being carried out improving the performance of existing frameworks of supply chain management system in order to make it more distributed in its operation. The next section discusses the problems associated with the existing system.
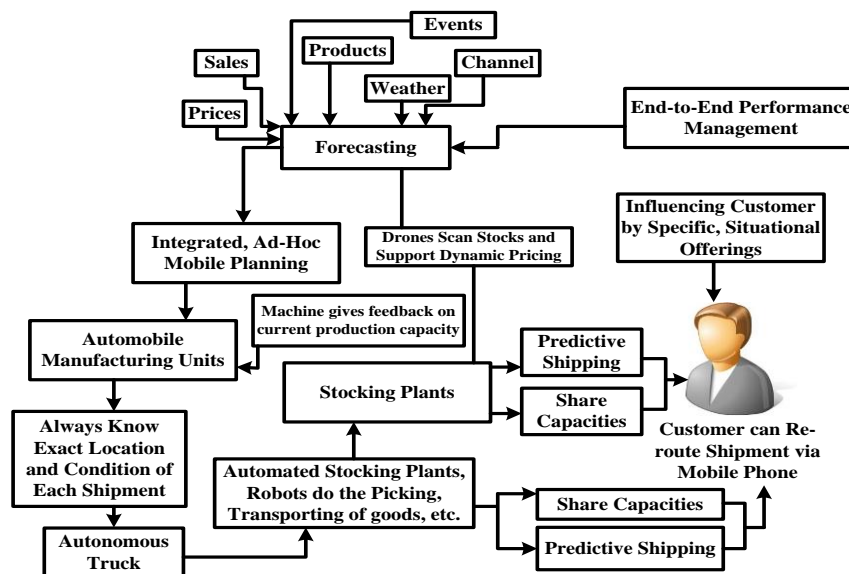

Figure 1. Supply chain 4.0 scheme

Various issues and problems have not been yet found to be addressed properly in the existing system. The first problem found unaddressed is that none of the existing approaches are found to implement the standard ideology of automation called as Industry 4.0. There is consensus in the literature that there is potential usage of enhancement and optimization based approaches, but few of the studies in the existing system are complying with the predictive operation that is demanded in the future. At the same time, there is also less evolution of an analytical model that could be claimed as a novel and unique modeling in supply chain operation and majority of such approaches only attempt to perform an assessment of existing supply chain operation under various case studies. Hence, unsolved problems are as follows:

- In order to perform automation of supply chain management system complying with Industry 4.0, it is essential to explore an effective intrinsic as well as extrinsic operator. This requires effective modeling considering the practical constraints that are found lacking in the existing system.
- Budget is one of the essential factors associated with supply chain management system. Under various dynamic and uncertain conditions of supply and demands, it is quite computationally challenging task even to evaluate a proper budgeting system.
- Developing a novel analytical model is required to perform a predictive optimization, which is quite difficult in the absence of various essential attributes to be identified for successful deployment of automation.

Therefore, the problem statement is there is a requirement of "*Developing a comprehensive supply chain automated framework compliance with Industry 4.0 for predictive optimization of its operation.*"

2.   RESEARCH METHOD

The implementation of the proposed system is carried out with respect to analytical research methodology where the prime focus is laid upon performing optimization. The target of optimization of the proposed system is to ensure a balance between compliance of Industry 4.0 automation standard and cost-effective deployment of supply chain management system. Figure 2 highlights the schema that has been adopted in the proposed system that consists of three core actors, namely, i) Automobile Manufacturing Units, ii) Stocking Plants, and iii) User Demands. The Automobile Manufacturing Unit generates its products considering certain cut-off limits of its product generation. The generated products are retained in Stocking Plants where there is a limit of storage. Hence, a better optimization process should ensure that there is always a space to store the units of products generated from manufacturing units. All the stored products are then shipped to the diversified geographical locations that can meet the demands of the users (or consumers, customers, etc).
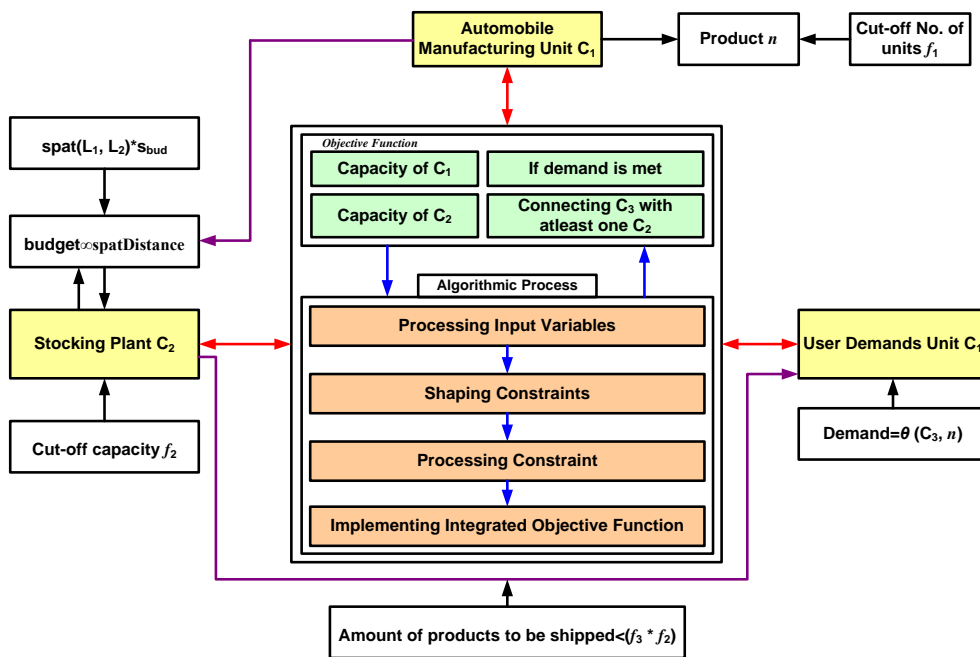

Figure 2. Proposed schema of adopted research methodology

However, there are many practical challenges to be considered while developing the proposed model that can always meet the trade-off between supply and demands. In order to ensure the practical viability of the proposed system, various constraints are also considered which form the objective function. The important constraints considered for the proposed system are i) capacity of products generated as well as storage factor in stocking plant and ii) constraint for terminating the trade-off between supply and demand. Apart from this, the proposed model also considers the budget as a prominent factor that is associated with

various forms of operation in the supply chain management system. In order to make the implementation practical and measurable, the proposed system also considers a significant algorithmic operation to ensure that implementation of the proposed system is streamlined with the analytical model developed for the proposed system. The proposed model is focused on ensuring that-for any forms of demands raised from the users, the proposed system should always ensure that there is the practical generation of the automobile units which is at par with the cut-off imposed by the system. At the same time, there is also a need that a better communication strategy is also constructed by knowing the information obtained about the reposition data obtained from the stocking plants. The complete scenario can be seen as a linearized problem, and hence, a linear optimization principle is applied to the proposed system. The complete model is, therefore governed by the linearized optimization principle. Illustrative information about the working principle is provided in the consecutive section of system design implementation.

3. SYSTEM DESIGN

This section discusses the concepts adopted for developing system design of proposed research work towards addressing feasibility problems associated with SCM taking the case study of the automotive industry.

3.1. The objective function of the system

The core objective function of the proposed system is to predict the user demands considering a case study of automotive units and optimal SCM process within the constraint of a number of Automobile Manufacturing Units, user demands, and Stocking Plants. The constraints considered for constructing the objective function of the proposed system are as follows:
- The increasing demands of the user for the various automotive types are highly unpredictable. It also varies according to government policies, competitor strategy, and many other factors. Therefore, the Stocking Plants/Automobile Manufacturing Units are dependent upon unpredictable User Demands.
- In a very dynamic context of automobile and automobile component's User Demands, the placement of Automobile Manufacturing Units and Stocking Plants should be flexible enough and synchronous to the demand and supply vision of automobile stakeholders in Industry 4.0 era, arriving at the standard template of system execution.

Therefore, according to the constraints mentioned above, it can be understood that the variable User Demands is a challenging part to be initialized while working on modelling. Moreover, the value of User Demands potentially affects the other two constraint factors, i.e., Automobile Manufacturing Units and Stocking Plants.

3.2. Implementation strategy

A closer look into the proposed system shows that the actors involved in the proposed system are highly linked with each other. This is the prime reason for applying linear optimization as a cost-effective automation process involved in the proposed model of supply chain management. Another strategy to implement is to consider the location of the manufacturing units, stocking plants, and diversified location of the retails where user demands are met. For this purpose, strategic implementation is carried out with respect to the level of manufacturing of the automotive products in all the manufacturing units. The proposed system also considers various constraints associated with the distributed operation associated with the manufacturing units connected to the stocking plants. It also considers various conditions as well as constraints associated with the amount of the manufactured units that are required to be transported from stocking plants to the location of the user demands. The next section discusses the system modelling that elaborates about the complete implementation strategy towards complying with Industry 4.0 automation standards.

3.3. System modelling

The core modelling of the proposed system is carried out considering three essential constraint parameters, i.e., Automobile Manufacturing Units (C_1), User Demands (C_2), and Stocking Plants (C_3). As all the parameters are in the form of variables, the study involves a fine-tuning parameter (α). Figure 3 exhibits the problem space, which shows the distribution of all constraint factors over a three-dimensional coordinate system.
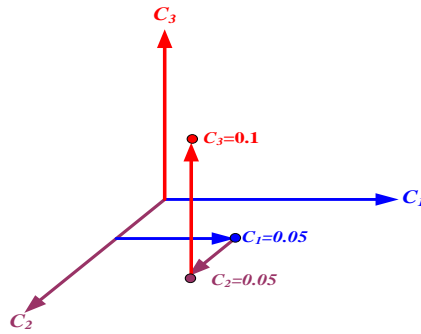
Figure 3. Position of adopted constraints in 3D problem space

The complete modelling is carried out considering a number of automobile/units N that are produced in automotive manufacturing units C_1. Therefore, an empirical representation of user demands could be represented mathematically as,

$$user\_demand \rightarrow \theta(C_3, n) \tag{1}$$

In the above expression (1), the variables θ, C_3, and n represent demand of a unit automobile, stocking plant constraint, and a single unit of automobile component n respectively. The proposed system considers the term demand as the number of automobile units that can be dispatched to the end clients over a specific duration of time. It will also mean that if the proposed system can generate such automotive products and it can successfully dispatch the targeted number of units than the user demands is said to be catered to. However, while hypothesizing such user demands, it is necessary to consider the capability factor that each automotive manufacturing unit (C_1) can generate along with a finite number of stocking plant ($C_{2.}$). In order to offer more practicality in the proposed modelling, the system also considers the better transportation probability, which is mathematically expressed as,

$$t_{ran} < thresh \tag{2}$$

The above expression represents a condition that is required to be satisfied in order to ensure the practical consideration of transportation of the automobile units. According to this expression (2), it can be stated as a condition to evaluate the quantity of automobile component n that is shipped from stocking plant C_2 to user demands C_3 over a limited range of cut-off time. The cut-off time factor there is computed as the scalar product of $f_1(n)$ and $f_2(C_2)$ that represents the rate of automobile throughput and the total size of C_2, respectively. In this line of evaluation, the study considers,

$$Generation(n, C_1) < f_1(C_1, n) \tag{3}$$

The above expression (3) will mean that the generation of manufactured automotive units n at C_1 is very much less than the cut-off number of automotive components f_1 with respect to C_1 and n. Therefore, in case the user demands obtain its automotive components from only one C_2, then the proposed system will initiate its evaluation for cost-effective structurization of C_3 to C_2.

3.3.1. Problem formulation

In order to formulate and consider the problem, the proposed system considers essential attributes while targeting to achieve optimization of feasibility factor in SCM. For this purpose, the attributes selected are p and q that can be mathematically formulated as follows,

$$Essential\ attributes = [p\ q]\ |\ p \rightarrow p(n, C_1, C_2)\ \&\ q \rightarrow q(C_3, C_2)$$

In the above expression of problem formulation, the first essential attribute p is associated with the quantity of the automobile components n that are shipped from C_1 to C_2 while q represents truth value of 1 and false value of 0. The truth value of 1 is assigned to q when the user demands C_3 is related to the stocking plant C_2. Hence, for better optimization, it is required to minimize the score of essential attributes cumulatively,

$$h \rightarrow \arg_{\min}[\sum(p_1) + \sum(q_1)] \tag{4}$$

In the above expression, the variable p_1 and q_1 are the function associated with **the budget factor** of three different constraints used in the proposed system. For potential adherence of the proposed system to the practicality of the research constraint implementation, there are various formulations of the constraints too as follows:

- Constraint-1: The first constraint formulation is associated with an overall limit that the automotive manufacturing unit can generate the production. This constraint is evaluated by checking the overall value of the essential attribute of p with respect to all the three constraints is less than f1.
- Constraint-2: The second constraint formulation is associated with the condition for fulfilling the demands of the user. This computation is carried out by cumulative product of demand θ and second essential attribute q. The analysis considers all the three constraints and unit product n.
- Constraint-3: This is the third constraint and is responsible for computing the overall space offered by C2 to stock its product. This constraint is evaluated by assessing the stocking plant C2 has enough capacity to retain the generate products from C1.
- Constraint-4: This fourth constraint performs multiple assessments viz. i) it confirms the connection of one user demands C3 with at least one stocking plant C2, ii) it also ensures that all the essential parameters of p should offer positive generation of products for better optimization of all the manufacturing units.

3.3.2. Algorithm implementation

The complete algorithm implementation is carried out based on two budget factor nbud and s_{bud}, which represents the budget required for manufacturing the automobile product and shipping, respectively. According to the proposed optimization concept, the *spatial distance* is another significant attribute that governs the cost-effective implementation of the automotive principle compliant of Industry 4.0 standard. The optimization principle implemented in the proposed concept ensures the fact that if the distance between the location where the user demand C_3 is met and the specific automotive product is effectively controlled, then, the budget involved in shipping from automobile manufacturing unit C_1 and the stocking plant C_2 is required to be considered. A concept is formulated where the spatial distance between the location L_1 and L_2 is considered for two respective facilities in order to compute the actual budget involved in transporting the automotive units. The empirical representation of the budget is as follows:

$$budget \rightarrow A*B \tag{5}$$

In the above expression (5), the variable A represents the spatial distance between L_1 and L_2, while variable B represents the shipping cost of an automotive product. The variable B is now represented as s_{bud} while another variable is crafted as n_{bud}, which represents budget in manufacturing the automotive product. The involvement of these two budget factors n_{bud} and s_{bud} offers more measurable value of cost-effectiveness. The steps of the proposed algorithm are as following:

Algorithm for performing feasibility optimization
Input: N, nbud, f1, f2, f3, sbud, θ
Output: O
Start
1. **For** i=1: C1
2. **For** j=1: C2
3. spat(C1C2)→|dist (pos(i)-pos(j))|
4. **End**
5. **End**
6. **For i**=1: C3
7. **For j**=1: C2
8. spat(C3, C2)→|dist(pos(i+C1+C2)-pos(j+C1+C2))|
9. **End**
10. **End**
11. For a=1: h   where h=total number of constraints
12. maxProd→∑p<f1
13. SucUsDem→comp(∑p)==θ*q
14. maxSPcap→→∑(1/f3)* θ*q<f2
15. SalesConnect→∑q==ones(C3)
16. **End**
17. **For** a=1:h

18. $O_1 \rightarrow \sum p.nbud$
19. $O_2 \rightarrow sbud*\sum comp*(spat(C3, C2))$
20. $O_3 \rightarrow \sum[(\theta.sbud*(\sum((spat(C3, C2)*q)))]$
21. $Ostruc=O1+O2+O3+O4$
22. $O \rightarrow \psi(Ostruc)$
23. **End**
End

The algorithm takes the input of N (number of automobile / units), n_{bud}(budget used for manufacturing), f_1 (limit of manufacturing of product), f_2 (limit of space in stocking plant), f_3 (throughput of automobile unit), s_{bud} (shipping budget incurred), θ (demand of automobile unit by users) which after processing yields O (optimal outcome). The processing of the proposed algorithm is carried out in many steps as follows-

- Processing Input Variables: In order to ensure proper compliance with Industry 4.0, there is a need to incorporate various charecteristics, e.g., predictive insights, demand settings, decision, information, and actions. Therefore, various input variables have been introduced in order to construct the problem with respect to randomness associated with the location of the various facilities. The next part of the input variable consideration is associated with budget involved, capacities of all the constraints, and demands.
- Shaping Constraints: The deployment of the proposed system is carried out by considering constraints linking with the spatial distance associating with the budget. The study considers all the possible value of C1 and C2 (Line-1 and Line-2) in order to compute the absolute spatial distance between the location of C1 and C2 (Line-3). The similar operation is also carried out for computing the absolute spatial distance between the location of C3 and C2 (Line-8)
- Processing Constraint: At present, the proposed algorithm consider 4 different types of constraint viz. i) the first constraint is associated with maximum production where the variable p is compared with f1, i.e., cut-off number of units (Line-12), ii) the second constraint is associated with assessing of the demands are catered up for all the location of user demand, and this is checked by comparing compact value of summation of p with the scalar product of demand θ and q variable (Line-13), iii) the third variable is associated with the complete capacity of the stocking plant C2 (Line-14), and iv) the fourth constraint is associated with the fact that each location of C3 should be connected with at least meeting up one demands.
- Implementing Integrated Objective Function: The objective function of the proposed system is directly connected with the budget involved in supply chain management. For all the constraints (Line-17), the study considers three objective functions O1, O2, and O3 connected with a cumulative budget of manufacturing, (Line-18), the budget of shipping products from C1 to C2 (Line-19), budget involved in shipping C2 to C3 (Line-20). Finally, all the objective functions are added in order to formulate a structure filled with values of the final objective function score (Line-21). Finally, a function ψ is applied, which mainly uses linear optimization for all the objective functions that bear a linear relationship with each other. The outcome is O, which show the best positioning of all the constraints of the proposed study, i.e., C1, C2, and C3 (Line-22).

4.   RESULT ANALYSIS

The implementation of the proposed study is scripted in MATLAB where the analysis is carried out considering α (fine-tuning parameter) to be in the range of 10-30, C_1 (automobile manufacturing units) is 0.06, C_2 (stocking plant) =0.06, and C_3 (user demand) is unity. Further, the system considers that there are 20-30 automobile units/components to be manufactured which are used for finally computing the entire budget involved in the proposed system. From the above visuals in Figure 4 and Figure 5, it can be seen that proposed system offers an analytical test-bed with positioning of the different actors (automobile manufacturing units, stocking plants, and user demands) over simulated area. Figure 4 highlights the different possibilities of positioning of varied actors while Figure 5 shows the best routes leading to different actors for fulfilling the supply and demand in the proposed system. Apart from this, the analysis framework also shows that the model is capable of exhibiting the degree of utilization of each actor present in the proposed system, which gives more decisive and predictive capability.

It is known that the optimization technique used in the proposed system have applied linear optimization technique on reducing the budget factor involved in the proposed study. However, there are various other approaches where machine learning has also been used in developing supply chain management [41, 42]. However, the problems addressed in the existing system is not similar to the proposed system; therefore, the proposed system performs simulation study by altering the optimization principle of proposed linear based to machine learning in order to obtain more specific outcomes in the similar test bed.
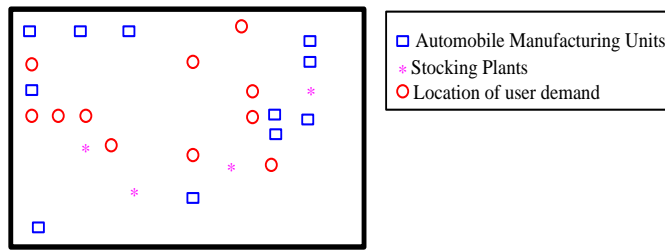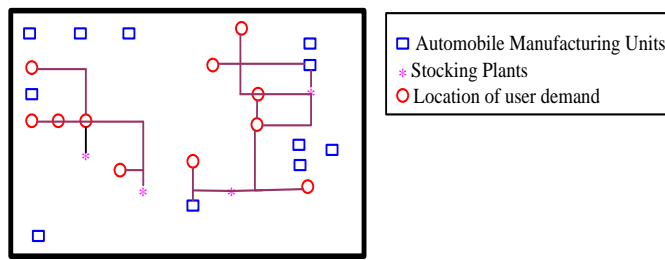
Figure 4. Localizing the actors of SCM

Figure 5. Obtaining best source for demand

The outcome shown in Figure 6 shows that the proposed system offers highly reduced processing time while the budget reduction capability of the proposed system is quite high as compared to the existing system. Therefore, the outcome shows that the proposed system offers a cost-effective predictive solution based on information of actors in compliance with the constraints derived from the practical world and is truly supportive of Industry 4.0 in Figure 7.
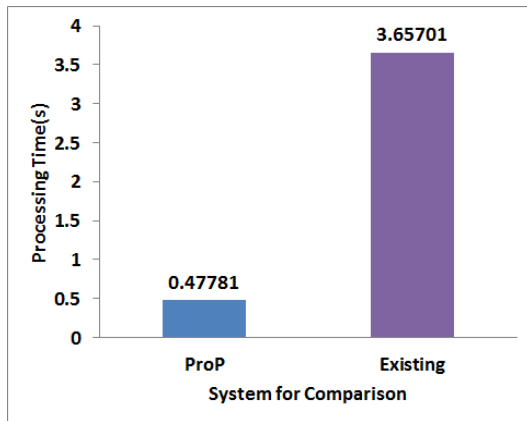

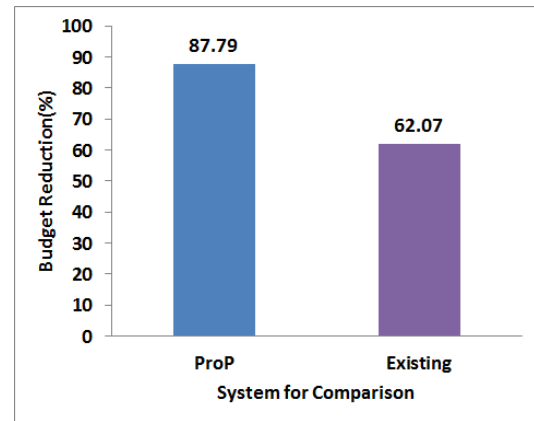Figure 6. Comparative analysis of processing time

Figure 7. Comparative analysis of budget reduction

5. CONCLUSION

The core idea of the proposed system is to evolve a predictive as well as preemptive modeling of supply chain 4.0 that adheres to the compliances of Industry 4.0 standard. The core contribution of the proposed system are as following i) the proposed model offers faster processing time with better budgeting control which potentially contributes towards financial planning and operation, ii) the model considers linear optimization over the linear constraints derived from the practical world scenario to offer better reliability of the modeling aspect, and iii) Multi-objective optimization principle is offered to cater up the dynamic trade-off between supply and demands in Industry 4.0. The proposed model can be considered in future research and improve the performance by adapting different optimization techniques.

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