Enhance VSM tool via integrating AHP and ARIMA in scheduling problem

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ABSTRACT: The diversity of demand and specifications has become a significant and mandatory for competitiveness issue among the factories to satisfy the customers in jerky demand case, it is originally a scheduling challenge. The main problem is facing the loss of factories their credibility in determining exact delivery time, due to its reliance on elements of the production chain, which begins with the selection of suppliers and then schedule human activities "NNVA", then machining time "VA". Customer satisfaction alerts these factories to quickly meet customers' orders (i.e., quantity, quality, price and delivery time) via selecting appropriate supplier and schedule a NNVA and VA activities resulted due to human intervenes. The AHP works on real data based on factor's weight (i.e., courtesy's suspicion) stands out preferable alternative, but if the selection depends on dynamic decision for future unknown, at this time the hybrid should be thrown. This paper proposed hybrid AHP and ARIMA as a neutral lean selection tongue. AHP fed by ARIMA's results to enhance the selection and achieving continuity via reducing a waste especially a lead time and scheduling setup time. The results of proposed methodology have been reviewed by VSM.

Keywords: AHP, ARIMA, Lead time, Value Stream Mapping, Tact Time, lean manufacturing.

INTRODUCTION: Lead time is the time spent between the customer requests and receives his order via shipment, or the interval between the initiation and the completion of a production process. This paper has carried out at Ideal-Standard factory for bathtubs in Egypt. The customer expectations are main top issue to face the length of lead-time, due to jerky's demands and specifications. The factories should be had quick adaptation system to decide them desire in competitiveness survive. This factory produces many different specification for bathtubs (i.e., make to order) strategy of lean manufacturing that seeks to produce a high level of throughput with a minimum of input, which requires suppliers' communication to prepare the raw materials (i.e., acrylic sheets with different quality and specifications) with the required specifications for the order. The supplier's delivery time consumes on average 25 days (for all bundles) till receipt of the raw material into inventory, which consumes financial and human resources without adding value [4], whereas the manufacturing process consumes 55 days as shown in Figure 11.1 and customer's receipt time consumes 2.67 days. The lead time equals on average 33620 min as illustrated in Figure-1, whereas the balance diagram shown in Figure-1-1 illustrates the bottleneck appears at inventory supplemented, the factory does not keep an inventory of finished bathtubs and only creates a certain customer demand. The maximum time consumed due to supplier and manufacturing processes. The factory should be respected the customer's request queue time for different orders. In an attempt to reduce the lead time, the factory decides to create an effective method select appropriate supplier and requested quantities via scheduling the orders that achieves minimum lead time, with respect to request's time. The ARIMA forecasts the customer's requirements that reflected on the supply chain, and load appropriate orders to produce in minimum time. Lean manufacturing considers practice that evaluates any exploitation of resources does not create value for the customer as a wasteful and should be eliminated. The problem translated into appropriate supplier's selection, who fulfills the requirement (quantity, quality, delivery time and presents a good price), which help the factory on competitiveness to survival and profitability of numerous factories Silver et al. [1], especially those experiencing increased market pressures for shorter delivery lead times of customized product. Therefore, select an AHP as a selection tool enhanced with forecast's tool famous for minimum error (e.g., ARIMA) to set the preference scale in step one of AHP as Lean development. More importantly, reductions in lead time increase flexibility to respond a customer orders [2]. Value Stream Mapping (VSM) is a language of Lean manufacturing that helps to control and streamline all processes via applying an oriented tools increases efficiency of manufacturing cycle [3]. Also, can be a transformed to online communication tool to manage a jerky demand [5]. The tact time is a one of VSM's visualization tool, indicates the extent of the factory's commitment to meet the demand on time, because it considers the time required for producing one bundle of salable quantity [6]. In the same context, multiple suppliers are a problem due to instability and non-homogeneity in specifications for production elements. Therefore, selecting an appropriate supplier and loading critical customers' orders in top the agenda of factories. The proposed Customer Satisfaction methodology (i.e., Self-fed database; CSM) have two sequential phases, the former aims to select the supplier who meet the customer requirements especially in delivery time, and the second aims to selecting appropriate orders to minimize the total manufacturing time, then customer delivery time.

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Methodology (Matureness steps):

Step 1: Theoretical construction of the approach (gather theoretical knowledge) and build the VSM database.
Step 2: Preparation of database sheet based on primary observations for suppliers and processing order time (collect field data; quantities, quality, and price $ per 20 cm^2 per unit related with quality).
Step 3: Data collection specially the delivery and tact time as a response factors to make data analysis via forecast with the supplier's commitment for at least the next quarter using ARIMA to set the factor's weight.
Step 4: Monitor the NNVA time represented in setup and changeover activities, during loading different orders, to make data analysis via forecast using ARIMA to set the factor's weight of orders that reduce the total lead time [12].
Step 5: Make documentation for supplier relationship and production line utilization with the level of achievement of the factory goal prelude to apply AHP.
Step 6: Database recursion after hybrid AHP and ARIMA for the significant field.
Step 7: Problem findings and suggest improvement scope.

The case study "Customer Satisfaction Methodology":

Phase I, Selecting appropriate supplier

Step-1: The factory deal with four suppliers through 40 previous purchase order for raw material and study each one for delivery time in the order of response for checking the first phase of proposed methodology. There are four factors shared in determining the supplier's relationship levels; **A**: Quantity/month, **B**: Quality six sigma scale, **C**: Price per 20 cm^2 per acrylic sheet unit, **D**: Payment per day. The response which used to tradeoff between suppliers is total Lead-time (supplier delivery time and the manufacturing time), which give the factory survive of competitiveness less than or equals 32 hrs. The next three tables shown the low and high levels of the four factors used in set the first three supplier's weight.

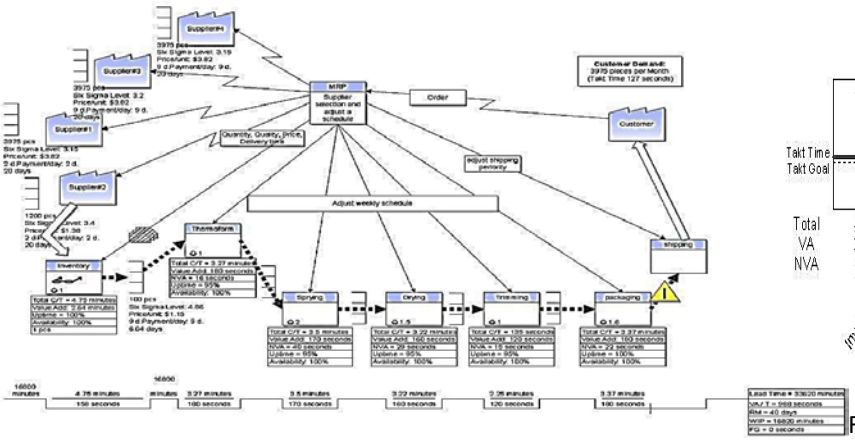

Fig (1): VSM in as-is situation

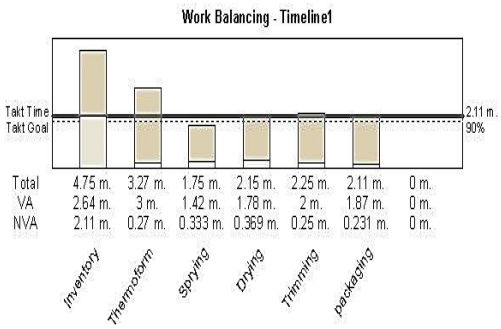

Fig (1.1): Tact time via balance diagram of as-is situation

Table (1) 1st Supplier field

	Low level	High level
A	1200	3975/month
B	3.15	4.99
C	$1.13	$3.82
D	2	9

Table (2) 2nd Supplier field

Low level	High level
1200	3975/month
3.4	5.6
$1.38	$3.87
2	9

Table (3) 3rd Supplier field

Low level	High level
1200	3975/month
3.2	5.84
$1.18	$3.82
1	9

The significant field for the first supplier as shown in Figure-2.1 is the quantity, whereas the second affects with the price field, and the third suppliers affects with the factory via all three fields as shown in Figures 2.2 and 2.3 respectively.

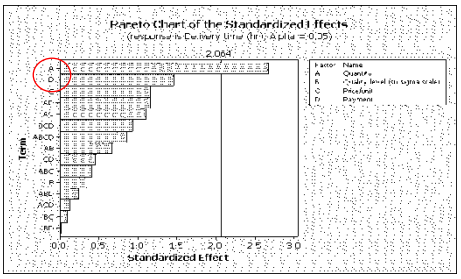

Fig (2-1): Pareto of 1st supplier significant fields

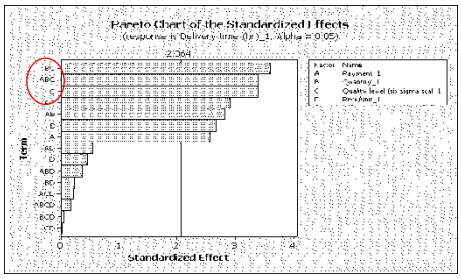

Fig (2.2): Pareto of 2nd supplier significant fields

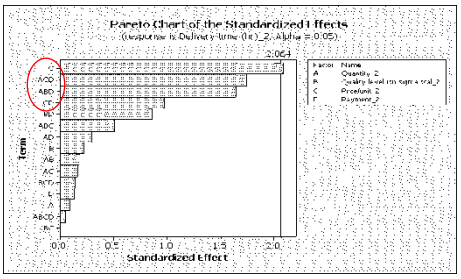

Fig (2.3): Pareto of 3rd supplier significant fields

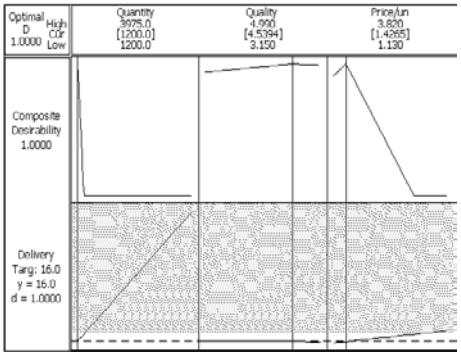

Fig (2.1.1): The optimization setting field for the first supplier

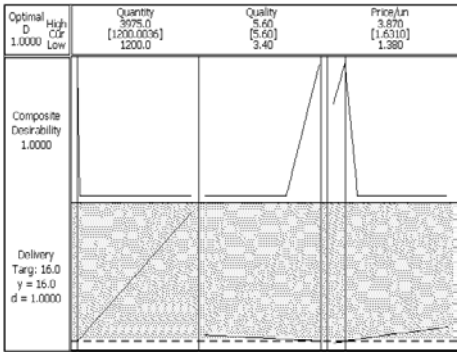

Fig (2.2.1): The optimization setting field for the second supplier

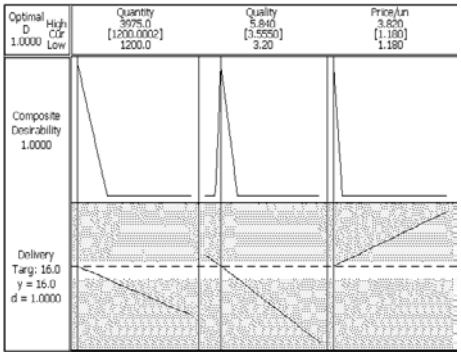

Fig (2.3.1): The optimization setting field for the third supplier

Step-2: Preparation of database sheet based on primary observations for suppliers (collect field data; quantity, quality, price per unit related with quality). The delivery time to start manufacturing may formulate in four equations as shown in Table (4)

Table-4: The delivery time equations for the suppliers

	Const.	A	B	C	AB	AC	BC	ABC
1st Supplier Eq(1)	39.958	-0.04395	-14.0067	8.9893	0.0164662	0.0096814	0.5534	-0.00390146
2nd Supplier Eq(2)	260.542	-0.20502	-69.3746	-63.5678	0.0562846	0.0626377	20.3555	-0.0176172
3rd Supplier Eq(3)	215.547	-0.0989901	-55.3520	-58.8638	0.0245042	0.0309157	18.2655	-0.00783818
4th Supplier Eq(4)	39.958	-0.04395	-14.0067	8.9893	0.0164662	0.0096814	0.5534	-0.00390146

Step 3: Data collection specially the delivery time as a response depending on the previous three criteria can be computed from Table (4) and make data analysis via forecast with the supplier's commitment for at least the next quarter using ARIMA to set the weight values for every supplier's criteria and use the residual error for set the above diagonal of periodization matrix. The Figures-3, 4 and 5 illustrate that the delivery time have general trend. Therefore, should treat the data with take second difference then cosh (2nd difference) [7 and 8] to fade this trend as illustrated in Figures-6, and only first difference and three exponential for other supplier data as shown in Figures 7 and 8.

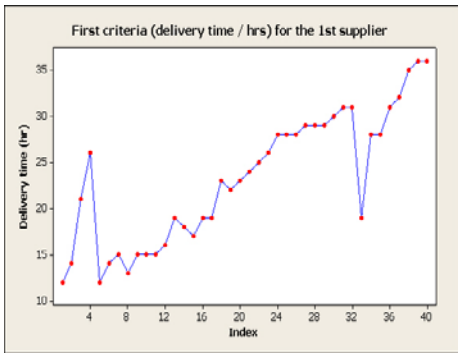

Fig (3): The general trend of delivery time for first supplier

Fig (4): The general trend of delivery time for second supplier

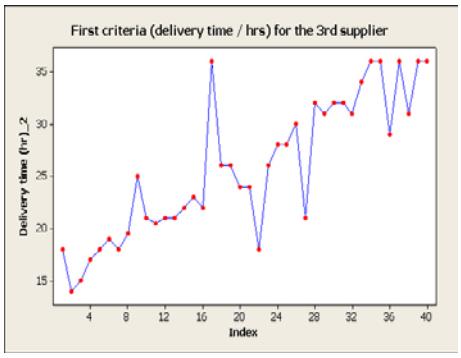

Fig (5): The general trend of delivery time for third supplier

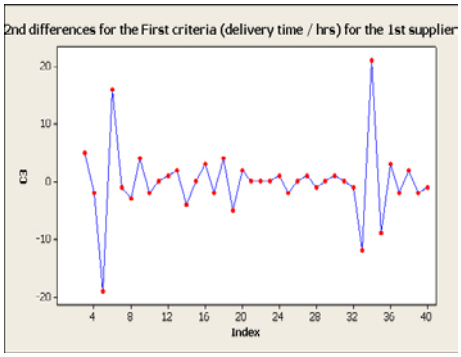

Fig (6): Fade the trend of delivery time for first supplier after second differences

Fig (7): Fade the trend of delivery time for second supplier after first differences

Fig (8): Fade the trend of delivery time for third supplier after first differences

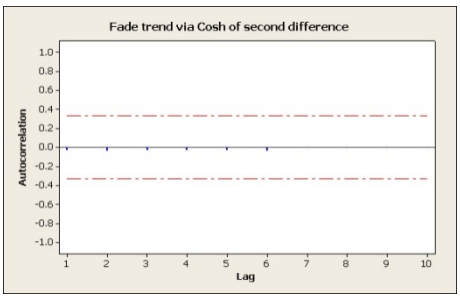

Fig (6.1): Fade the trend of delivery time for first supplier after second differences

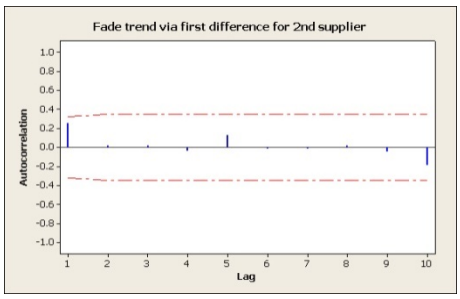

Fig (7.1): Fade the trend of delivery time for second supplier after first differences

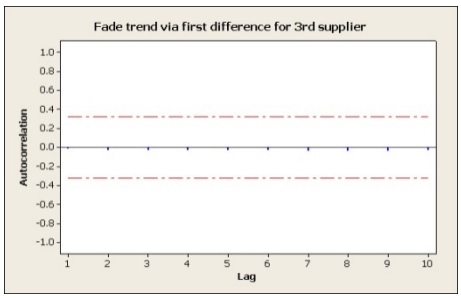

Fig (8.1): Fade the trend of delivery time for third supplier after first differences

To check from fading the trend extracts ACF and PACF for all suppliers, which significantly different about zero till spike (9) and not lay in confidence range $-0.315 \leq r_k \leq 0.315$. LIung & Box declares the acceptance the original assumption $H_0: \rho_1 = \rho_2 = \Delta\Delta = \rho_k = 0$ of transformed data for 1st supplier, because $Q.stat = LBQ\ (TBF) = 0.34 < x^2{}_{(10,0.05)} = 2.228$ [8], and belief of stationary in delivery time data. And make the same test to the other suppliers' delivery time data. Select the near distribution (i.e., exponential) that reduces the data trend and repeat taking the differences for its value till fade the trend $\nabla Y_{t\ (logarithmic)} = Y_{t(logarithmic)} - Y_{t-1(logarithmic)}$ as illustrated in Figure-13, but must repeat the LBQ test to the first difference $LBQ\ (TBF_{first\ diff}) = 0.52 < x^2{}_{(10,0.05)} = 2.28$. Therefore, should not take the second difference for the DT data and accept H_0. Which should in parallel to the axis of the joints, to prove the absence of the general trend as illustrated in (Figure-15) then preferable [d=3]. The forecasted ARIMA (1, 3, 1) results for criteria (quantity, quality, price), whereas ARIMA (1, 1, 2) for payment criteria and ARIMA (2, 3, 1) for lead time criteria, its relations listed as shown in Table-5, 6, 7 and 8 for suppliers.

Table-5: The Forecasted quality level weighted for AHP

Forecasted	Lower	Upper	Average	Relations		
4.60893	2.52842	6.68944	4.60893	1.0000		
3.95621	1.84854	6.06388	3.95621	1.16498	1.0000	
2.73238	0.54061	4.92414	2.73237	1.68678	1.447901	1.0000
4.60893	2.52842	6.68944	4.60893	1.0000	0.858379	0.592844

Table-6: The Forecasted price/unit/20cm² weighted for AHP

Forecasted	Lower	Upper	Average	Relations		
1.72214	0.53827	2.90601	1.72214	1		
3.80119	2.77770	4.82468	3.80119	0.453053	1	
3.11665	2.26379	3.96950	3.116647	0.552562	1.219641	1
1.72214	0.53827	2.90601	1.72214	1	2.207248	1.809752

Table-7: The Forecasted Payment/day weighted for AHP

Forecasted	Lower	Upper	Average	Relations		
5.9530	1.6991	10.2070	5.953033	1		
5.20584	0.42536	9.9863	5.205833	1.143531	1	
4.41619	0.70490	8.12747	4.416187	1.348003	1.178807	1
5.9530	1.6991	10.2070	5.953033	1	0.874484	0.741838

Table-8: The Forecasted Lead-time/hrs. weighted for AHP

Forecasted	Lower	Upper	Average	Relations		
31.0618	13.2691	48.8545	31.0618	1		
37.0541	16.2261	57.8821	37.0541	0.838282	1	
38.1464	25.9566	50.3361	38.14637	0.814279	0.971366	1
31.0618	13.2691	48.8545	31.0618	1	1.192915	1.22808

Step 4: Make documentation for supplier's criteria relationship with the level of achievement of the factory goal prelude to apply AHP [9], because it help the factory to adjust the strategic inventory guarantee the production continuity till receipt the supplier's message, and in minimum level to besiege the holding cost effect.

Table-9:The quantity criteria analysis for all suppliers

Quantity	S #1	S #2	S #3	S #4		S #1	S #2	S #3	S #4
Supplier #1	1	1	1	1		0.25	0.25	0.25	0.25
Supplier #2	1	1	1	1		0.25	0.25	0.25	0.25
Supplier #3	1	1	1	1		0.25	0.25	0.25	0.25
Supplier #4	1	1	1	1		0.25	0.25	0.25	0.25

Table-10: The quality level criteria analysis for all suppliers

Quality level	S #1	S #2	S #3	S #4
Supplier #1	1	1.165	1.6868	1
Supplier #2	0.8584	1	1.4479	0.8584
Supplier #3	0.5928	0.6907	1	0.5928
Supplier #4	1	1.165	1.6868	1

S #1	S #2	S #3	S #4
0.2898	0.2898	0.2898	0.2898
0.2487	0.2487	0.2487	0.2487
0.1718	0.1718	0.1718	0.1718
0.2898	0.2898	0.2898	0.2898

Table-11: The Price criteria analysis for all suppliers

Price	S #1	S #2	S #3	S #4
Supplier #1	1	0.4531	0.5526	1
Supplier #2	2.2072	1	1.2196	2.2072
Supplier #3	1.8098	0.8199	1	1.8098
Supplier #4	1	0.4531	0.5526	1

S #1	S #2	S #3	S #4
0.1662	0.1662	0.1662	0.1662
0.3668	0.3668	0.3668	0.3668
0.3008	0.3008	0.3008	0.3008
0.1662	0.1662	0.1662	0.1662

Table-12: The Payment criteria analysis for all suppliers

Payment	S #1	S #2	S #3	S #4
Supplier #1	1	1.1435	0.5526	1
Supplier #2	0.8745	1	1.1788	2.2072
Supplier #3	1.8098	0.8483	1	1.8098
Supplier #4	1	0.4531	0.5526	1

S #1	S #2	S #3	S #4
0.2135	0.3319	0.1683	0.1662
0.1867	0.2903	0.359	0.3668
0.3863	0.2463	0.3045	0.3008
0.2135	0.1315	0.1683	0.1662

Table-13: The Lead-time criteria analysis for all suppliers

Lead-Time	S #1	S #2	S #3	S #4
Supplier #1	1	0.8383	0.8143	1
Supplier #2	1.1929	1	0.9714	1.1929
Supplier #3	1.2281	1.0295	1	1.2281
Supplier #4	1	0.8383	0.8143	1

S #1	S #2	S #3	S #4
0.2262	0.2262	0.2262	0.2262
0.2698	0.2698	0.2698	0.2698
0.2778	0.2778	0.2778	0.2778
0.2262	0.2262	0.2262	0.2262

The periodization matrix fed by compensation in the equations appeared in Table-4 prelude to make a score for every supplier's criteria as shown in Table-14.

Prioritization Matrix	Set via parameters in Table-4				
	A	B	C	D	E
A	1	2	3	2	7
B	0.5	1	2	2	5
C	0.3333	0.5	1	2	2
D	0.5	0.5	0.5	1	2
E	0.1429	0.2	0.5	0.5	1

A	B	C	D	E
0.4038	0.4762	0.4286	0.2667	0.4118
0.2019	0.2381	0.2857	0.2667	0.2941
0.1346	0.119	0.1429	0.2667	0.1176
0.2019	0.119	0.0714	0.1333	0.1176
0.0577	0.0476	0.0714	0.0667	0.0588

Step 5: Database recursion after hybrid AHP and ARIMA for the significant fields**,** the weight is an average value from A to E for every supplier after check the consistency index [10]. This database represents a closed loop take forecasted ARIMA (p, d, q) for different and fed AHP to enhance continuity of results with time (i.e., Matureness situation).

Table 14: The final score for every supplier based on average forecasted data for all criteria

Summary	A		B		C		D		E		Final Score
	Weighting	Score	Weighting	Score	Weighting	Score	Weighting	Score	Weighting	Score	
Supplier #1	0.397	0.250	0.257	0.290	0.156	0.166	0.129	0.220	0.060	0.226	0.242
Supplier #2	0.397	0.250	0.257	0.249	0.156	0.367	0.129	0.301	0.060	0.270	0.276
Supplier #3	0.397	0.250	0.257	0.172	0.156	0.301	0.129	0.309	0.060	0.278	0.247
Supplier #4	0.397	0.250	0.257	0.290	0.156	0.166	0.129	0.170	0.060	0.226	0.235

Step 6: Problem findings and suggest improvement scope aims to deals with the supplier#2 as illustrated in Figure-9 in the next manufacturing quarter, and arrange the orders as illustrated in Figure-10, whereas Figure-12 illustrates the VSM after maturity and depends on forecasted many criteria or deals with many suppliers to get main objective, which is customer satisfaction.

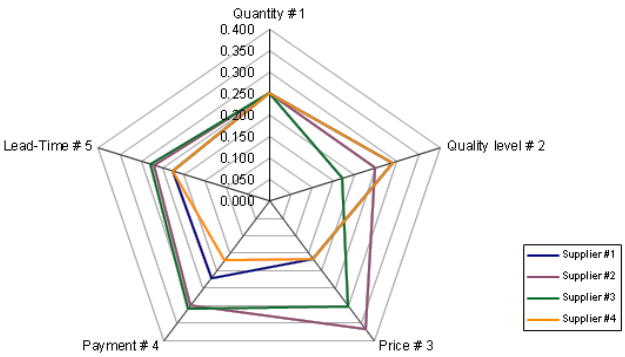

Fig (9): The preferable selection based on forecasted data

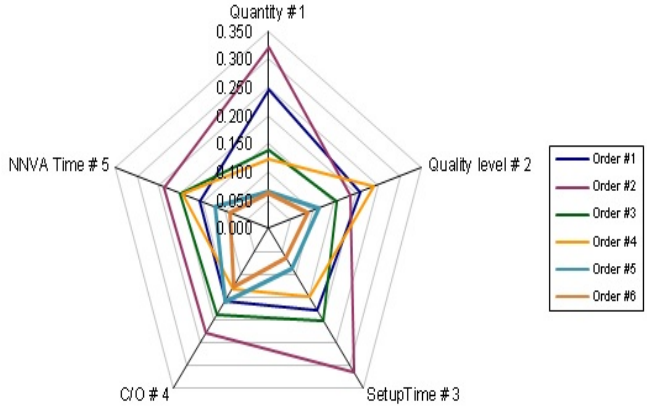

Fig (10): The preferable orders selection based on forecasted data

Phase II, selecting appropriate order

By the same way, select the preferable orders reduces the total delivery time, In this phase assumes that the factory receives six different orders, which have different executing time (Eq. 1) with different specifications and jerky quantities, taking into account the time of registration of the order. In this phase, improve a previous published rule aims to reduce the total lead-time [5]. The acronyms used in the proposed equation "Customer Satisfaction Methodology" selection orders to reduce the total manufacturing time. The database in this context relies on feeding with different orders, the customer registration time and the executing time (Eq. 1.1). In this phase, rely on ARIMA to forecast with NNVA time and fed the AHP with it aided with CSM equation to adjust the weight for all significant factors such as (quality level, quantities, setup time, C/O, NNVA time).

$$ET = VA_{time} + \frac{NNVA_{time} + SetUp_{time} + C/O_{time}}{Order\ Quantity} \text{..... (Eq. 1)}$$

$ES_{final\ Order}$: Earliest start "NNVA" time of final selected order estimated for certain customer.

$ET_{final\ Order}$: Executing "VA" time of final selected order.

$ES_{first\ Order}$: Earliest start "NNVA" time to first selected order estimated via ARIMA.

$ES_{predecessor\ Order}$: Earliest start "NNVA" time of predecessor of first selected order estimated via ARIMA.

$ET_{predecessor\ Order}$: Executing "VA" time for selected order.

$ET_{first\ Order}$: Executing "VA" time for first selected order estimated via ARIMA.

$$CSM = \frac{(ES_{final\ selected\ Order} + ET_{final\ selected\ Order}) - ES_{first\ selected\ Order}}{(ES_{Predecessor\ selected\ Order} + ET_{Predecessor\ selected\ Order}) + ET_{first\ selected\ Order}} \text{..... (Eq. 1.1)}$$

The equation's nominator indicates the NNVA time appeared between the orders execution, which should be checked via ARIMA. The denominator represents the total time required to finish the orders in time. The Eq. (1.1), depends on network based schedule form, which explains through following steps to increase the customer satisfaction [11]:

Table 15: Customer Registration time for different six orders

Orders|	Customer registration (Forecasted NNVA via ARIMA for Execute time)					
1	3 (1)	1 (3)	2 (6)	4 (7)	6 (3)	5 (6)
2	2 (8)	3 (5)	5 (10)	6 (10)	1 (10)	4 (4)
3	3 (5)	4 (4)	6 (8)	1 (9)	2 (1)	5 (7)
4	2 (5)	1 (5)	3 (5)	4 (3)	5 (8)	6 (9)
5	3 (9)	2 (3)	5 (5)	6 (4)	1 (3)	4 (1)
6	2 (3)	4 (3)	6 (9)	1 (10)	5 (4)	3 (1)

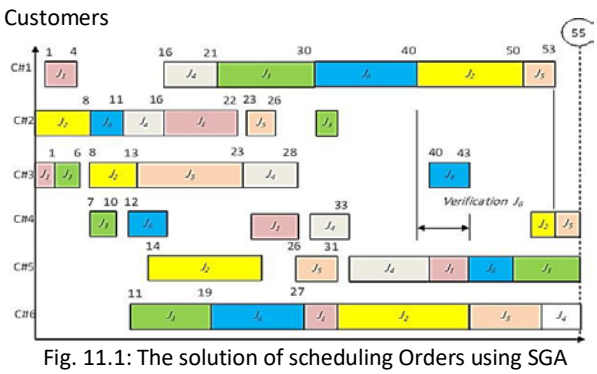

Fig. 11.1: The solution of scheduling Orders using SGA supported with supplier #2.

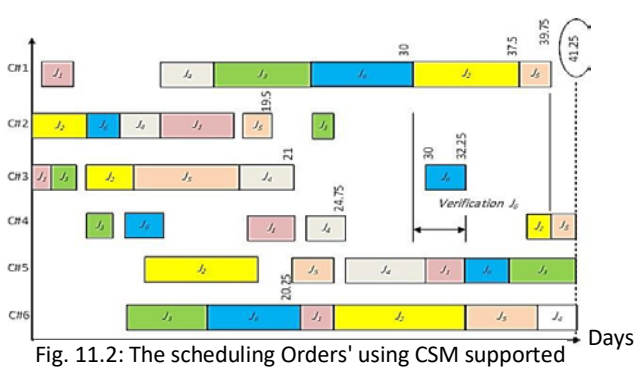

Fig. 11.2: The scheduling Orders' using CSM supported with supplier #2.

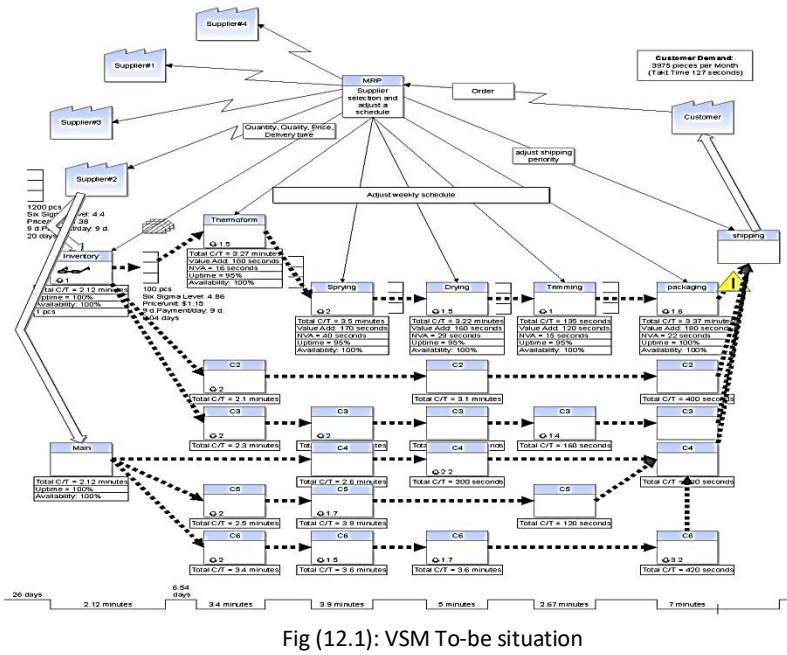

Fig (12.1): VSM To-be situation

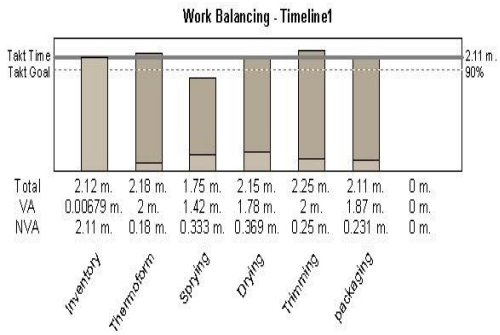

Fig (12.2): Tact time via balance diagram of to-be situation

Conclusion:

The selection problem tackled by many methods, one of the most famous is AHP, but it limited because of their accreditation on some values adjusted via experts (i.e., suspicion of non-neutrality). Therefore, ARIMA used to analysis the data collected for suppliers' criteria data through 40 previous different jerky demands, and transform the data to stationary case and forecast with all criteria for all supplier, and take an average to adjust the weight of each criteria and score, which set via DOE equations for every supplier. All this analysis fed AHP to start presenting a preferable supplier alternative which serves our objective, where exact quantities with high quality and less price in shortest time. The delivery time reduced from 80 days to 51.6 days. The forecasted ARIMA (1, 3, 1) results for criteria (quantity, quality, price), whereas ARIMA (1, 1, 2) for payment criteria and ARIMA (2, 3, 1) for lead time criteria. In the same context, used ARIMA (1, 3, 1) for executing six different orders. Its relations listed as shown in Table-5, 6, 7 and 8 for suppliers. Table-16 shown the improvement after implementing AHP aided with ARIMA analysis model. The results prove the right to pick up all next three manufacturing cycle from the second supplier. Table-17 shows the extracting of forecasting data from Minitab statistical package for implementing ARIMA as suggested above.

Table-16: Comparative analysis for AHP aided with ARIMA intervenes

		Average			Improvement
		Before	After	Actual	
Supplier Selection Phase I					
The forecasted quantity bundle [80 bathtubs]		Jerky	1200	1200	100%
The forecasted delivery time [day]		25.021	19.545	21.6	21.85%
	Tact time [min]	2.11	2.11	2.11	--------
	VA/T [sec] of Supermarket's Inv.	968	810	810	16.32%
	WIP [min]	16820	2766	2840	83.11%
	Manufacturing Acceleration [day]	55	41.25	43	25%
	Lead-Time for six customers [day]	40.02/2 shift	32.6/1 shift	32.42/1 shift	59.2%
The forecasted quality level		3.2	5	4.86	36%
The forecasted price/unit		2.2	1.1466	1.31	62.95%
The forecasted payment/days		9	18.4149	13.5	28.45%
Orders executing Phase II					
The Avg. forecasted Setup time for different orders [day]		9	2	2.3	77.77%
The Avg. forecasted C/O time for different orders [hrs.]		38	12	12	68.42%
The Avg. forecasted NNVA time for different orders [day]		12	8	8	33.34%
The forecasted accuracy		--------	Avg. improvement		97.8298%

Table-17: The forecasted data for different suppliers criteria

Supplier #1	Supplier #2	Supplier #3	Supplier #4
Period Forecast Delivery time 41 36.5122 42 37.0184 43 37.5012	Period Forecast Delivery time 41 **35.5446** 42 **35.7060** 43 **36.1421**	Period Forecast Delivery time 41 35.9506 42 36.1453 43 36.9220	Period Forecast Delivery time 41 36.5122 42 37.0184 43 37.5012
Period Forecast quality level 41 3.95621 42 3.11652 43 2.90174	Period Forecast quality level 41 **4.6089** 42 **4.9265** 43 **5.5733**	Period Forecast quality level 41 3.95621 42 3.11652 43 2.90174	Period Forecast quality level 41 3.95621 42 3.11652 43 2.90174
Period Forecast Price/unit (20cm^2) 41 3.80119 42 4.32730 43 4.71892	Period Forecast Price/unit (20cm^2) 41 **1.72214** 42 **1.12629** 43 0.59142	Period Forecast Price/unit (20cm^2) 41 3.80119 42 4.32730 43 4.71892	Period Forecast Price/unit (20cm^2) 41 3.80119 42 4.32730 43 4.71892
Period Forecast Payment/day 41 3.4693 42 3.7697 43 5.9230	Period Forecast Payment/day 41 **13.5459** 42 **18.0812** 43 **23.6177**	Period Forecast Payment/day 41 3.8508 42 2.5577 43 4.3609	Period Forecast Payment/day 41 3.4693 42 3.7697 43 5.9230

Future work:

The main objective is besieging the jerky demand phenomena via forecasting model (i.e., ARIMA) fed a selection tool as AHP till maturity case to adjust the selection of appropriate supplier at each order and adjust products selection schedule to reduce the manufacturing cycle time, really it's a scheduling problem. The researcher hope for transform the proposed methodology to coded database helps the stakeholders in decision making in neutral case in any ERP systems and transform the VSM to intelligent VSM.

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