SIMULATION FOR REDUCING ENERGY CONSUMPTION OF MULTI CORE LOW VOLTAGE POWER CABLE MANUFACTURING SYSTEM

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ABSTRACT

This paper proposes an integrated simulation manufacturing system with ARENA 7.01 to reduce the energy consumption in production line. There are two projected propose scenarios implemented to simulate this matter i.e. more economical machine use, and process cluster scenarios. The two scenario will be compared with normal scenario that represent current system will also model with ARENA. Comparatively based on normal scenario, the propose models succeeded reduce by 2.85% for more economical machine use and 3.17% for process cluster.

Keywords: Simulation, energy saving, manufacturing system

1.0 INTRODUCTION

Substantial amount of energy and other resources consumption involve in manufacturing industry. Therefore energy consumption contributes the great portion of the total manufacturing cost. Hence, the energy consumption reduction can significantly reduce the whole cost of manufacturing work. However complexity of the system and expensive cost in experimenting new physical manufacturing line may result this is difficult to implement. Thus, the existing process is still remaining to be applied in manufacturing line.

The information that breakdown of energy consumption within manufacturing facilities or processes may enables to test new manufacturing line improvement. The test can be done by numerical estimation without need of actual physical system. Number of approaches can be applied on the matter. And to replicate the complexity of the system at the same time reasonable cost for experimenting new manufacturing line, simulation of the system is suggested. The simulation is simplified for a controlled system study to minimize the effects of variables other than the independent variable. This action increases the result reliability with comparative to actual system.

This paper models the actual manufacturing system to propose alternative solution on existing process by simulation. The organization of the paper begin with literature study of related previous work. The operating environment and statement of the study elaborates in Section 3, Section 4, and Section 5. Based on the experiment, discussion on result and conclusion clarifies in following sections.

2.0 PREVIOUS STUDY

Simulation had been widely using tool for manufacturing system analysis and design for more than 30 years (Smith, 2003, p.157). This shows that simulation has proven to be an extremely useful analysis tool. Energy consumption has become main concern in manufacturing industry due to the increased energy costs and associated environmental impact. Based on previous study experience, it is expected that this study can reduced energy consumption of a manufacturing system through simulation. This section explains the validity used of ARENA software and the trend of simulation of energy consumption in many industries. Thus, this makes this section stapled the confidence on this study in the field of simulation, energy saving and manufacturing system.

2.1 Use of ARENA Software

There are number of software applicable for simulation and for this study, ARENA Version 7.01 simulation software will be used. The advantages use of the software due to it is proven workable as a simulation in industries and research study. In industrial application the software simulated in MTS Medical Technologies for medical packaging system; Simulation Modelling Services Pty Ltd for mining industry; North Carolina Public Health Information Network on E.coli outbreak preparedness and response; and Canada Forces for deployment personnel shortage, are to name a few.

Many studies used ARENA software to simulate the supply-chain and logistics management. In the field of supply-chain, Patil, Jin, & Li (2011) studied to save cost for supply-chain and Tannock et al. (2007) measured the supply-chain performance. And for logistic management optimizing the loading and unloading in warehouse studied by Liong, & Loo, (2009) and Kara, Rugrungruang, & Kaebernick, (2007) used the software to estimate cost of a reverse logistic network for collecting end-of-life appliances.

In the field of manufacturing, wide of area had been covering by researcher in simulation with ARENA such as Altuger, & Chassapis (2009) in bread packing line performance and equipment utilization**;** Ferreira et al. (2008) simulate automobile closed-loop assembly line; John, & Jenson Joseph, (2013) simulate factory layout to measures the efficiency of production; Zahraee et al. (2014) used the software to eliminate the bottlenecks and waiting times in the production line; Yalcin, & Namballa (2005) simulate in real-time control of automated flexible manufacturing systems; Kumar & Phrommathed, (2006) improved a manufacturing process by mapping and simulation of critical operations; Melouk et al. (2013) optimized system based on decision support tool for steel manufacturing by simulation; and Costa et al. (2008) manipulated the software as a tool for planning material delivery system in manufacturing lines. While even widely used of the software in manufacturing system research, application in power cable manufacturing is still never been done. Based on previous study it is possible to apply the study in multi core low voltage power cable manufacturing system.

2.2 Energy Consumption in Simulation

Simulation energy consumption in forecasting and profiling energy usage in buildings studied by Neto & Fiorelli (2008) and Heiple & Sailor (2008). In manufacturing industry simulation used by Herrmann et al. (2011) to planning of manufacturing systems based on energy usage oriented; Herrmann & Thiede, (2009); Dietmair & Verl, (2009); Heilala et al. (2008); and Rahimifard, Seow, & Childs (2010) studied on energy efficiency in manufacturing companies via simulation; by monitoring and analysis of energy consumption Vijayaraghavan & Dornfeld (2010); Mouzon, Yildirim, & Twomey (2007); and Seow, & Rahimifard (2011) suggested a method to reduce energy usage in manufacturing system. By simulation model of machining work energy consumption, a model that optimized energy use suggested by He et al. (2012) and Dietmair & Verl (2008).

None of previous research ever study to simulate manufacturing system in the environment of power cable manufacturing environment. In addition the simulation manipulation to estimate the energy use increases speedy interest for research study due to it is so much economical. Thus the fuse of simulation to simulated power cable manufacturing system with the aim to energy consumption reduction is open a gap for a good research study.

3.0 THE CABLE MANUFACTURING OPERATING ENVIRONMENT

The actual system of the cable manufacturing applied in this study. The system is scope down from the complexity of the actual system that manufacture multiple segment of cables and wire product. The cable marketing is competitive, thus for business protection the name of the referred company, production output and certain technical details will kept confidential. The general process of cable manufacturing is as follow.

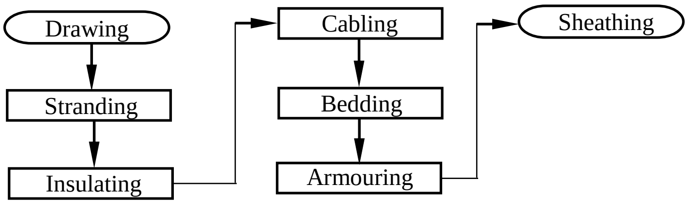

Figure 1: Schematic Low Voltage PVC Insulated PVC Sheathed Armoured Cable Manufacturing Process

The Production Department (PD) operates twenty four hour from Monday to Friday and off day be on Saturday and Sunday. The Management Department operates from 8.00 am to 5.00 pm from Monday to Friday and from 8.00 am to 12.30 pm on Saturday. Since the request from customer is more than PD can support in usual operation, PD frequently operates on Saturday and Sunday. As this is internationally known company, the request also comes from Africa and South East Asia. The tricky thing is the customer request in accordance to their customized or deflection from referred standard. The special requests such as unique colour, termite repellent based compound or hot chilli based compound, special test for compound or fire test for completed cable, and compound from other standard to be applied in referred standard. Each process required additional cost for set up time on every machine of each process, especially when various cable size process at the same time. These are the kind of dynamic conditions the company need to handle. In this study, standard cable design is in focus so that the attempt to reduce energy used can be clearly formulated.

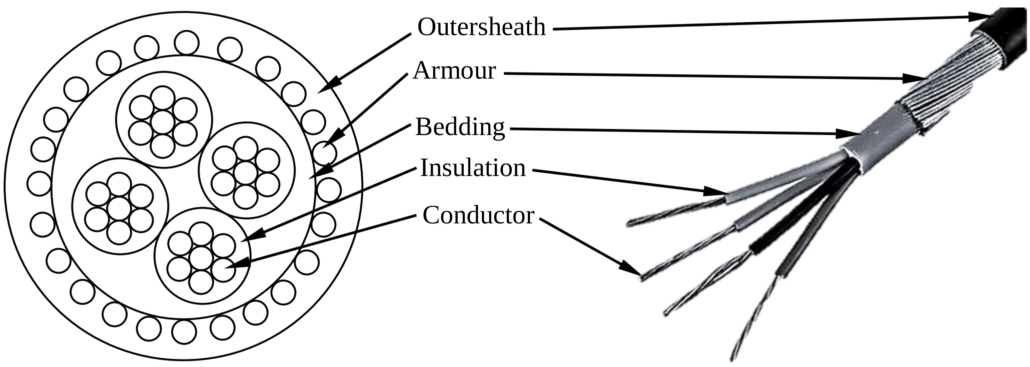

Figure 2: Four Cores Cable Construction

Operation of manufacturing cable started with Copper Rod that supply by supplier accordance to certain standard such as British Standard, IEC and ASTM. The material compound which are PVC, polypropylene (PE), cross-link polypropylene (XLPE), semi-conductive compound will be tested prior from manufacturing process to ensure that the material is comply with the referred standard. Some other material such as additive compound, tapes and amour rods will be tested referring to standard requirement. And the sequence of processes are following the structure of the cable design. For example four core cable as shown in Figure 2. The first layer is conductor, in this case cable of four conductors need to be processed. After that, insulation coated each of conductor is the second layer. Then the core will be twisted and apply with a compound called as bedding is the third layer. For protective purpose the armour wire will be applied as fourth layer. Finally the last layer covered with outersheath which is made of compound.

For the detail, this paragraph discussed on conductor wire and compound used for the cable. Copper rod will undergoes diameter reduction by process of drawing. This process required two stages if the wire size for cable's conductor is smaller than 1.53mm of diameter. The smaller diameter of rod or wire will be twisted a-rope-like together in stranding process. The amour wire is made of steel supplied by the supplier accordance to requirement standard. It serves to protect cable that installed underground. For machine use consideration, number of wire correlates with number of bobbin (to place the wire) to set to the machine. PVC compound has some degree of flame retardant, and resistance to oils and chemicals, it has found suit in many applications including low power cable. It's characteristics -- flexibility, resistance to temperature, resistance to adverse environmental situations and low cost; make it most suitable material to manufacture cables. There are three layers of compound i.e. insulation, bedding, and outersheath; that structured the cable formation, PVC compound can be one of it. All extrusion machines are applicable for these layers which differentiate by the external diameter size of the layer.

The machines output can be categorised into two. The class from drawing machine output is based conductor material mass. The rest is in class that is based on cable length. Certain process such as stranding, and insulation required addition length the product length required since the process of stranding and insulation required longer length to undergo cabling process. The practice of single process manufacturing is believed not economical for energy consumption. However this is done in the production plan practice on day-to-day basis. In order to test save energy production line a practical approach shall be taken. Rearranging production line may need huge amount of cost. Simulation is the alternative for solving the matter in more economical way.

4.0 THE CONTROLLED OF THE STUDY

Since wide variety of cable can be manufactured by the company. This study will scope down into controlled cases with one type of cable and selected number of core, design and size of cable. The length of the cable also pre-determine earlier to set the completion of cables manufacturing. The selected cable design is a set of multicore cables with PVC Insulated PVC Sheathed Armoured Cables. Table 1 shows the process and layers required for the cable, length of cable and cable output for each process.

Table 1: The Manufacturing Processes with Machine Output Per Shift of Operation for Cables

Cable & length	Cable Size	Drawing 1	Drawing 2	Stranding	PVC Insulation	Cabling	PVC Bedding	Armouring	PVC Sheath
Cable 1 11km	4 Cores * 10mm² (7/1.35mm)	Henrich A	Henrich B	Buncher 1000	EX-90	Cort 1.6	EX-90	Cort 1.6	SC-90
	Per Shift	10700 kg	2609 kg	28km	25km /core	2800m	9500m	2500m	7500m
Cable 2 15km	4 Cores * 6mm² (7/1.04mm)	Henrich A	Henrich B	Buncher 1000	EX-90	Cort 1.6	EX-90	Cort 1.6	SC-90
	Per Shift	10700 kg	2470 kg	24km	28km /core	2800m	9000m	2500m 3hr	8000m
Cable 3 15km	12 Cores * 4mm² (7/0.85mm)	Henrich A	Henrich B	Buncher 1000	EX-90	Cort 1.6	SC-90	Cort 1.6	SC-90
	Per Shift	10700 kg	2623 kg	22km	28km /core	2500m	8700m	2200m	7000m
Cable 4 13km	3 Cores * 185mm² (37/2.52mm)	Henrich A	No need	KOA 54B	SC-90	H-2.6 D/T	EX-150	H-2.6 D/T	EX-150
	Per Shift	10562 kg	-	5.5km	12km /core	3000m	7700m	2000m	5800m

For number of reasons testing and packing process will be excluded in this process. The test is conducted during the manufacturing process. The test also conducted prior to manufacturing process to ensure any new material used is in accordance to the referred standard. Thus no additional time required for manufacturing. In addition energy consumption for the test is too small that can be ignored for energy consumption. For the case of packing, which is done in Packing Department, management has never include any energy consumption for production cost estimation. Thus, any reference regarding to energy consumption for the matter has no record.

5.0 MODEL EXPERIMENTATION

The 'process best flow' suggested by PD based on optimum output as indicated in Table 1. The suggested process is based on experience, design, and the size of cable. To cut down the energy consumption, the two propose systems are based on using lesser energy machine and process cluster. For example machine with lower energy consumption can do the same work as higher energy consumption machine. However the output of the machine is at lower rate may reflect the total amount of energy consumption. Process cluster scenario is expected will reduce small amount of energy use. These are the alternative configurations of process flow to be simulated in logical condition. For this experiment the two scenarios details are follow; and the normal scenario that represent current system will also model with ARENA for comparison purpose.

- *Scenario 1 - Changing propose of 'process best flow' to the more economical machine use*
  In this experiment revising machine use is proposed which lower energy use machine is utilised more than machine with higher energy consumption. On top of that, suggestion also made to manipulate additional energy use for each machine setup. This is required to change materials according to particular grade, the number of bobbin used, and change of extrusion size and so on. The setup process also applied certain amount of energy at estimation of 50% that production process.

- *Scenario 2 - Revising the current practice of single process to process cluster*
  The cluster processing experiment involves Drawing 1, Drawing 2, Stranding, Cabling, and Armouring processes. Since drawing process required two stages, the first stage draw down up to one size which is 2.52mm. The second process is done also in group by Henrich B where in this case only drawing die is needed for change to certain size required. Cable 1, Cable 2, and Cable 3 will run in a cluster for stranding process since the number of wire which bobbin required is same and the wire size is approximately similar. For the same reason Cable 1 and Cable 2 run in cluster for cabling process since their cable core number is same. The armouring process for Cable 1 and Cable 2 will run in a cluster since their external bedding diameter is approximately similar and the amour wire size and number of wire is similar.

ARENA software used the term Model as the complete works on the system. The system completes with a flowcharts which each sub-chart called as Modules. In this experiment, the constructed model completes with the Modules i.e. Create, Process, Separate, Decide, Record, and Dispose. Based on the scenarios, ARENA 7.01 software is applied to model the system. Figure 3 and figure 4, show the scenario of normal practice and this flowchart also then modified with lesser energy consumption machine capacity for scenario 2. Figure 5 models the process cluster scenario. The models then simulated the modules and characteristics applied on them.

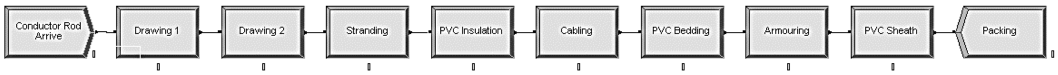

Figure 3: Arena Model - Normal and Economical Machine Use Scenarios of Cable 1, Cable 2, and Cable 3

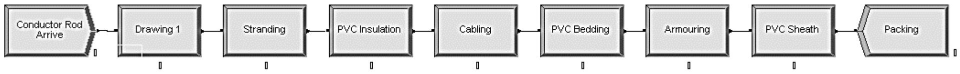

Figure 4: Arena Model - Normal and Economical Machine Use Scenarios of Cable 4

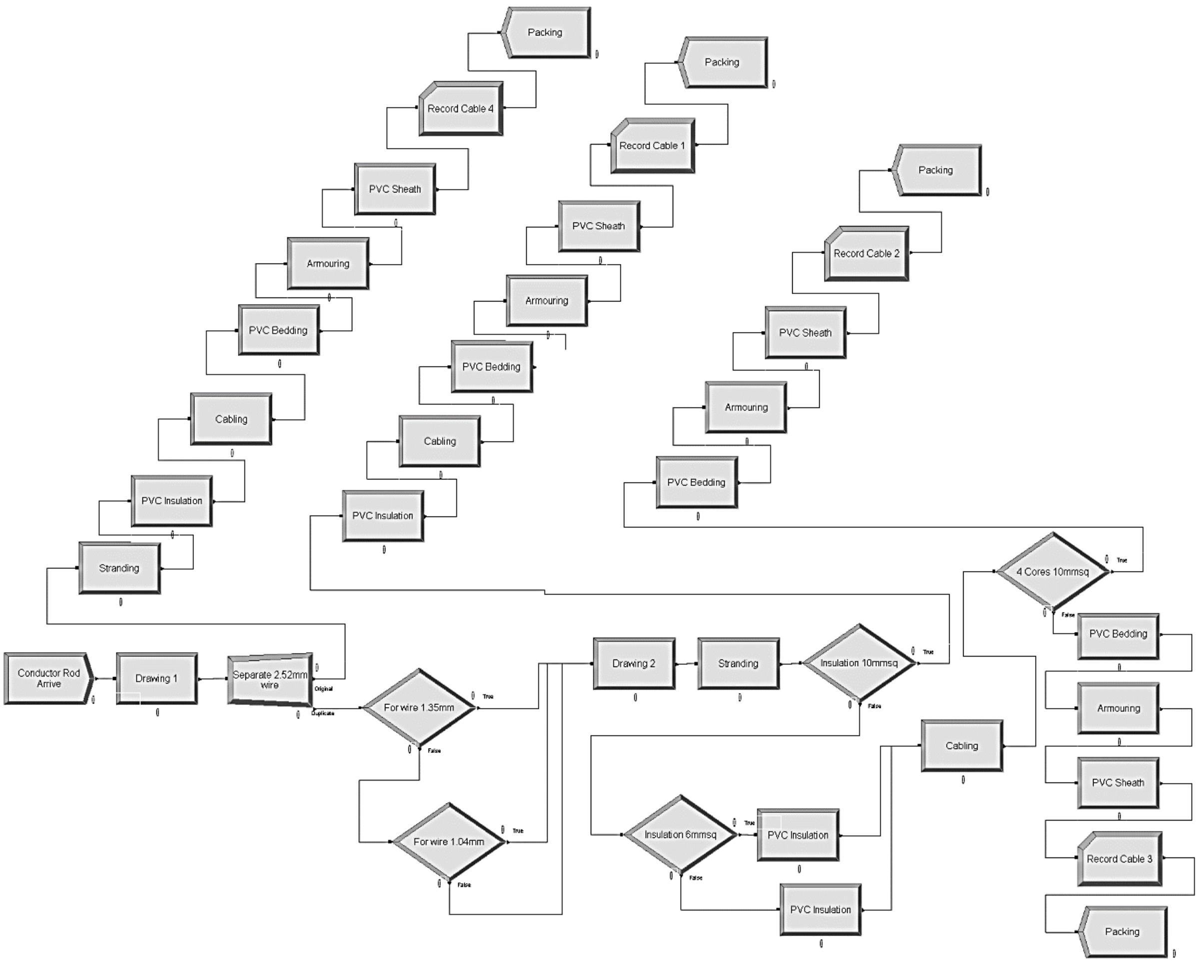

Figure 5: Arena Model for Process Cluster Scenario of Cable 1, Cable 2, Cable 3, and Cable 4

The process module is the primary module to model with ARENA. It represents the machine, resource, queue, and the entity delay time. For simplification and easy notification, the process module is named by the processes instead of the machines name. This helps to understand the flow of the process. Initially the module also need setting by check the Report Statistics so that the statistic can be tapped at Report Module. As a part of simulation output, collecting statistics on resource utilization, number in queue, and time in queue at each of the operations. These three statistics are automatically collected at Record modules placed before packing sub-chart.

Addition to figure 5 with special module to complete the process flow. The use of Separate Module in the model provides the ability to duplicate entity to accomplish output of 2.52mm wire of conductor – in this case the output then sent to all cables accordingly. The module treats batch of entities as a single entity referring to Drawing 1 process. Then the module split the batch into its individual parts for another section in this model. Two duplicate entities created that allow manufacturing drawing process for the other three sizes of cable. Decide module with type of 2-way by chance; 2-way by condition; N-way by chance; and N-way by condition. The classification of size of cable on two layer of decision making will be modelled with Decide module. The Decide module is defaulted as 2-way by Chance type from the four selection. The percent characteristics is derived from the conductor mass used for drawing process and from cable length for insulation process.

6.0 DATA COLLECTION AND RESULT

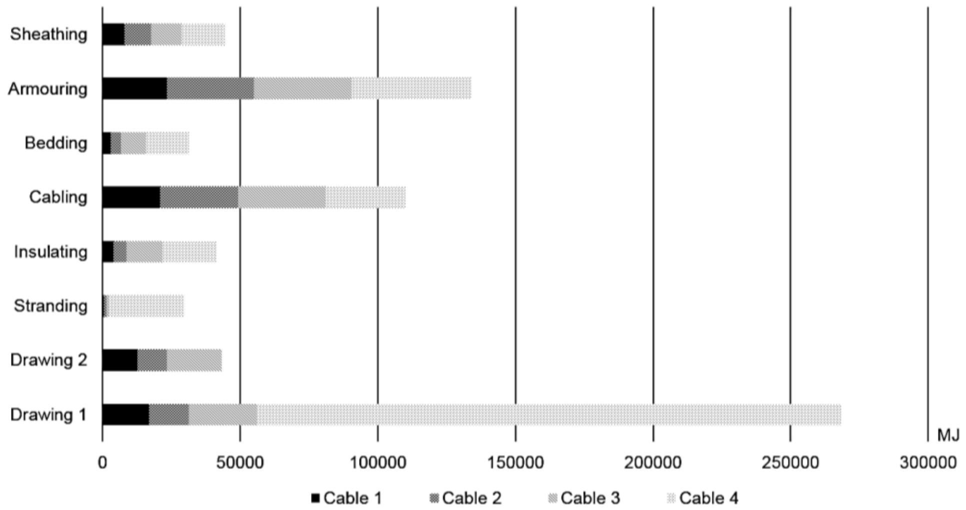

Figure 6: The Machines' Energy Consumption for Normal Scenario

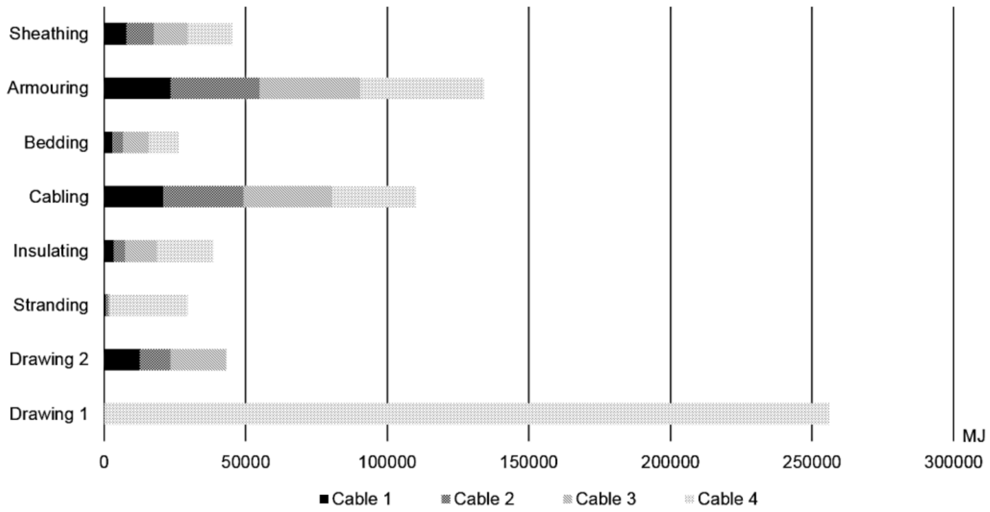

Figure 7: The Machines' Energy Consumption for Economical Machine Use Scenario

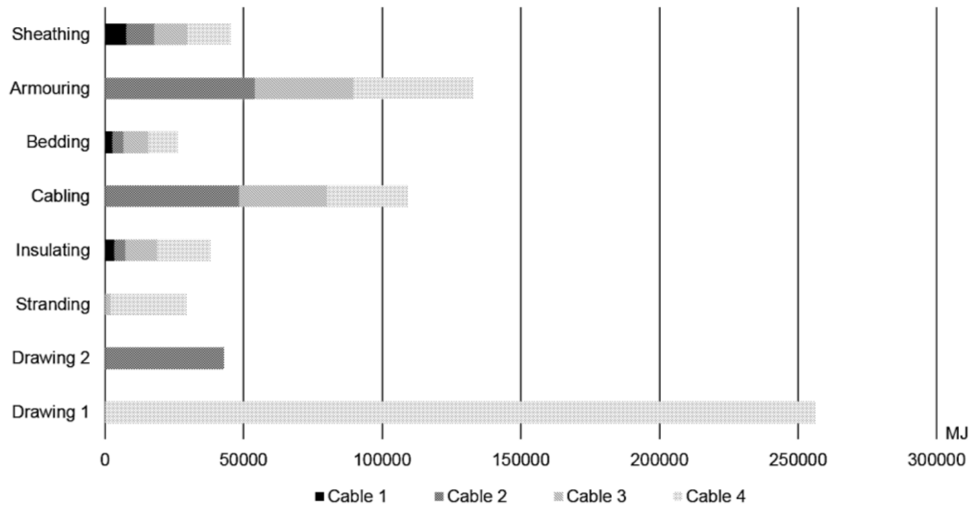

Figure 8: The Machines' Energy Consumption for Process Cluster Scenario

Table 2: The Result of Energy Consumption for the Three Scenarios

	Normal Scenario				Economical Machine Scenario				Process Cluster Scenario			
	Cable 1	Cable 2	Cable 3	Cable 4	Cable 1	Cable 2	Cable 3	Cable 4	Cable 1	Cable 2	Cable 3	Cable 4
Drawing 1	**Henrich A**	**Henrich A**	**Henrich A**	**Henrich A**	**Henrich A**	**Henrich A**	**Henrich A**	**Henrich A**	**Henrich A**	**Henrich A**	**Henrich A**	**Henrich A**
hr req (hr)	2.91	2.36	4.72	48.15	2.91	2.36	4.72	48.15	0	0	0	58.27
Eng (MJ)	16891.2	14515.2	24710.4	212328	16891.2	14515.2	24710.4	212328	0	0	0	256046.4
Drawing 2	**Henrich B**	**Henrich B**	**Henrich B**	**Henrich B**	**Henrich B**	**Henrich B**	**Henrich B**	**Henrich B**	**Henrich B**	**Henrich B**	**Henrich B**	**Henrich B**
hr req (hr)	11.94	10.21	19.26	0	11.94	10.21	19.26	0	0	43.27	0	0
Eng (MJ)	12577.68	10896.12	19692.72	0	12577.68	10896.12	19692.72	0	0	43030.44	0	0
Stranding	**Buncher 1000**	**Buncher 1000**	**Buncher 1000**	**KOA 54B**	**Buncher 1000**	**Buncher 1000**	**Buncher 1000**	**KOA 54B**	**Buncher 1000**	**Buncher 1000**	**Buncher 1000**	**KOA 54B**
hr req (hr)	3.14	5	5.45	18.91	3.14	5	5.45	18.91	0	0	14.91	18.91
Eng (MJ)	584.64	819	875.7	27186.12	584.64	819	875.7	27186.12	0	0	2067.66	27186.12
Insulating	**EX-90**	**EX-90**	**EX-90**	**SC-90**	**EX-70**	**EX-70**	**EX-70**	**SC-90**	**EX-70**	**EX-70**	**EX-70**	**SC-90**
hr req (hr)	14.08	17.16	51.48	31.2	14.08	17.16	51.48	31.2	25	28	28	10
Eng (MJ)	3926.16	4702.32	13350.96	19423.8	3365.28	4030.56	11443.68	19423.8	3365.28	4030.56	11443.68	19423.8
Cabling	**Cort 1.6**	**Cort 1.6**	**Cort 1.6**	**H-2.6D/T**	**Cort 1.6**	**Cort 1.6**	**Cort 1.6**	**H-2.6D/T**	**Cort 1.6**	**Cort 1.6**	**Cort 1.6**	**H-2.6D/T**
hr req (hr)	31.43	42.86	48	34.67	31.43	42.86	48	34.67	0	74.29	48	34.67
Eng (MJ)	20982.996	28266.192	31541.4	29297.7	20982.996	28266.192	31541.4	29297.7	0	48293.388	31541.4	29297.7
Bedding	**EX-90**	**EX-90**	**SC-90**	**EX-150**	**EX-90**	**EX-90**	**SC-90**	**SC-90**	**EX-90**	**EX-90**	**SC-90**	**SC-90**
hr req (hr)	9.78	13.33	13.79	17.93	9.78	13.33	13.79	15.76	9.78	13.33	13.79	15.76
Eng (MJ)	2842.56	3737.16	9082.26	15784.56	2842.56	3737.16	9082.26	10549.44	2842.56	3737.16	9082.26	10549.44
Armouring	**Cort 1.6**	**Cort 1.6**	**Cort 1.6**	**H-2.6D/T**	**Cort 1.6**	**Cort 1.6**	**Cort 1.6**	**H-2.6D/T**	**Cort 1.6**	**Cort 1.6**	**Cort 1.6**	**H-2.6D/T**
hr req (hr)	35.2	48	54.55	52	35.2	48	54.55	52	0	83.2	54.55	52
Eng (MJ)	23385.24	31541.4	35715.06	43335	23385.24	31541.4	35715.06	43335	0	53970.84	35715.06	43335
Sheathing	**SC-90**	**SC-90**	**SC-90**	**EX-150**	**SC-90**	**SC-90**	**SC-90**	**EX-150**	**SC-90**	**SC-90**	**SC-90**	**EX-150**
hr req (hr)	11.73	15	17.14	17.93	11.73	15	18.46	17.93	11.73	15	18.46	17.93
Eng (MJ)	7858.62	9801	11072.16	15784.56	7858.62	9801	11856.24	15784.56	7858.62	9801	11856.24	15784.56
Total hr	**142.21**	**175.92**	**236.39**	**242.79**	**142.21**	**175.92**	**237.71**	**240.62**	**55.59**	**266.25**	**221.19**	**250.74**
Total Eng (MJ)	**89049.096**	**104278.392**	**146040.66**	**363139.74**	**88488.216**	**103606.632**	**144917.46**	**357904.62**	**14066.46**	**162863.388**	**101706.3**	**401623.02**

Note: hr req – Hour Required; Eng – Energy Consumption; hr – hour; MJ – Mega Joule.

Based on the attempt to energy consumption reduction the experiments started with normal scenario to make comparison. This scenario and with the other two scenarios the simulated to determine the output from the simulation. Based on the experiments Table 2 tabled result of each scenario. This result used to derive charts of figure 6, figure 7, and figure 8. Based on the charts they show that the Drawing 1 process uses the highest amount of energy use – 268448.8MJ for Normal and Economical Machine Use and 256046.4MJ for Process Cluster. The process consumes the lowest energy is Stranding process – 29465.46MJ for Normal and Economical Machine Use; 43030.44 MJ for Process Cluster. Based on percentage Bedding process reduce the highest amount of energy which 16.67% from 31446.54MJ to 26211.42MJ. The incremental is for Sheathing process about 1.76%.

Table 3: The Manufacturing Process Energy Consumption Based on Scenarios

Scenario	Normal	Economical Machine		Process Cluster	
		-	Diff (%)	-	Diff (%)
Energy Consumption (MJ)	702507.89	682518.53	2.85	680259.17	3.17
Hour Required (hr)	791.31	790.59	0.06	793.77	0.31

Based on the scenarios the overall energy consumption and hour required result are shown in Table 3. Comparatively the reduction of energy at 3.17% effects too small of production output hour required which 0.31% different. The small difference is due to time for machine set up reduce longer time required for using machine with low energy use. Overall this show positive outcome, which for the 3.17% lowering energy use to extra time required is only about 0.31% increase.

7.0 CONCLUSION

The clear cut of achieving better levels of energy saving in manufacturing cable is by reducing energy consumption. However implementing energy saving probably may cause lower output for the production line. Realizing the advantages of simulation technique to replicate a real-world system, this study integrates the use of ARENA to help cable manufacturer develop a model to determine different alternative that may reduce energy consumption.

This paper demonstrates the applicability of quantitative modelling with ARENA software which apply queueing theory. This study enables production engineer to analyse the structure and behaviour of the production line. And the primary advantage is by simulation cost required for experimentations are too small.

Based on this study, few suggestions are put forward. Firstly, the management has to set an optimal time delay or output that can be tolerated by the customer. Once the optimal time has been set, the management can utilize the simulation model by experimenting with different scenarios to obtain the best combination of processes that reduce energy consumption and the production line capacity. As a result both output and the most economical energy consumption can be predicted. Secondly, our observation revealed that although planned has already made for the production however there is still need for urgent request by customer. Thus, a certain condition has to decide by management so that the precedence of the production list can be prioritized.

REFERENCES

Altuger, G., & Chassapis, C. (2009, December). Multi criteria preventive maintenance scheduling through arena based simulation modeling. In *Winter Simulation Conference* (pp. 2123-2134). Winter Simulation Conference.

Costa, B., Dias, L. S., Oliveira, J. A., & Pereira, G. (2008, June). Simulation as a tool for planning a material delivery system to manufacturing lines. In *2008 IEEE International Engineering Management Conference* (pp. 1-5). IEEE.

Dietmair, A., & Verl, A. (2008, November). Energy consumption modeling and optimization for production machines. In *2008 IEEE International Conference on Sustainable Energy Technologies* (pp. 574-579). IEEE.

Dietmair, A., & Verl, A. (2009). A generic energy consumption model for decision making and energy efficiency optimisation in manufacturing. *International Journal of Sustainable Engineering*, *2*(2), 123-133.

Ferreira, L. P., Gómez, E. A., Lourido, G. P., Lázaro, A. R., & Pérez, C. L. (2008). Comparative Analysis between analytical and Arena simulation models applied to an Automobile closed-loop assembly line, modelled as a network of closed loops. In *Proceedings of 25th International Manufacturing Conference: Manufacturing and Design—The Next Generation (IMC2008), Ireland, 3rd-5th September*.

John, B., & Jenson Joseph, E. (2013). Analysis and Simulation of Factory Layout Using ARENA. *International Journal of Scientific and Research Publications*, *1*, 3.

He, Y., Liu, B., Zhang, X., Gao, H., & Liu, X. (2012). A modeling method of task-oriented energy consumption for machining manufacturing system. *Journal of Cleaner Production*, *23*(1), 167-174.

Heiple, S., & Sailor, D. J. (2008). Using building energy simulation and geospatial modeling techniques to determine high resolution building sector energy consumption profiles. *Energy and Buildings*, *40*(8), 1426-1436.

Heilala, J., Vatanen, S., Tonteri, H., Montonen, J., Lind, S., Johansson, B., & Stahre, J. (2008, December). Simulation-based sustainable manufacturing system design. In *2008 Winter Simulation Conference* (pp. 1922-1930). IEEE.

Herrmann, C., Thiede, S., Kara, S., & Hesselbach, J. (2011). Energy oriented simulation of manufacturing systems–Concept and application. *CIRP Annals-Manufacturing Technology*, *60*(1), 45-48.

Herrmann, C., & Thiede, S. (2009). Process chain simulation to foster energy efficiency in manufacturing. *CIRP journal of manu. science and tech.*, *1*(4), 221-229.

Kara, S., Rugrungruang, F., & Kaebernick, H. (2007). Simulation modelling of reverse logistics networks. *International Journal of Production Economics*, *106*(1), 61-69.

Kumar, S., & Phrommathed, P. (2006). Improving a manufacturing process by mapping and simulation of critical operations. *Journal of Manufacturing Technology Management*, *17*(1), 104-132.

Liong, C. Y., & Loo, C. S. (2009). A simulation study of warehouse loading and unloading systems using Arena. *Journal of Quality Measurement and Analysis*, *5*(2), 45-56.

Mark Davidson (October 09, 2013), 28 Manufacturing Metrics that Actually Matter – The one we rely on. LNS Research. Access on 25 August 2016 via http://blog.lnsresearch.com/blog/bid/188295/28-manufacturing-metrics-that-actually-matter-the-ones-we-rely-on

Melouk, S. H., Freeman, N. K., Miller, D., & Dunning, M. (2013). Simulation optimization-based decision support tool for steel manufacturing. *International Journal of Production Economics*, *141*(1), 269-276.

Mouzon, G., Yildirim, M. B., & Twomey, J. (2007). Operational methods for minimization of energy consumption of manufacturing equipment. *International Journal of Production Research*, *45*(18-19), 4247-4271.

Neto, A. H., & Fiorelli, F. A. S. (2008). Comparison between detailed model simulation and artificial neural network for forecasting building energy consumption. *Energy and buildings*, *40*(12), 2169-2176.

Patil, K., Jin, K., & Li, H. (2011, December). Arena simulation model for multi echelon inventory system in supply chain management. In *Industrial Engineering and Engineering Management (IEEM), 2011 IEEE International Conference on* (pp. 1214-1217). IEEE.

Rahimifard, S., Seow, Y., & Childs, T. (2010). Minimising Embodied Product Energy to support energy efficient manufacturing. *CIRP Annals-Manu. Tech.*, *59*(1), 25-28.

Seow, Y., & Rahimifard, S. (2011). A framework for modelling energy consumption within manufacturing systems. *CIRP Journal of Manu. Science and Tech.*, *4*(3), 258-264.

Tannock, J., Cao, B., Farr, R., & Byrne, M. (2007). Data-driven simulation of the supply-chain—insights from the aerospace sector. *International journal of production economics*, *110*(1), 70-84.

Vijayaraghavan, A., & Dornfeld, D. (2010). Automated energy monitoring of machine tools. *CIRP Annals-Manufacturing Technology*, *59*(1), 21-24.

Yalcin, A., & Namballa, R. K. (2005). An object-oriented simulation framework for real-time control of automated flexible manufacturing systems. *Computers & industrial engineering*, *48*(1), 111-127.

Zahraee, S. M., Golroudbary, S. R., Hashemi, A., Afshar, J., & Haghighi, M. (2014). Simulation of Manufacturing Production Line Based on Arena. *Advanced Materials Research*, (933).