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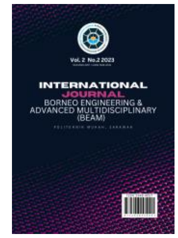

A Discrete Event Simulation Case Study of Energy Consumption and Time Required for Medium Voltage Power Cable Manufacturing

Full Paper

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Abstract

Cable manufacturing is a very competitive industry. Hence, to face with this competitiveness manufactures must offer the similar product at a lower price. The fuse of this issue and manufacturer capacity resulted the idea to have a new more productive production line. This requires expected to have an ideal production line – economical production line and shorter processing time. For having the new line, experimentation on the line is compulsory to make sure it is more productive than the existing one. Though, because of having new physical experimentation is too costly and difficult due to the size and weight of the machines, discrete event simulation is proposed. Therefore, this paper aims to propose an alternative production line flow that is more optimal in terms of energy consumption and time required to manufacture the selected cable through discrete event simulation. The model will be developed and simulated by Arena Software. This model initially is verified and validated by production line technical staff through Face and Historical Data approaches. Fortunately, the proposed alternative production line outperformed standard production line. The lesser energy consumption (0.75%) and time required (3.28%) can be obtained through the alternative production line. Thus, this is a winnable strategy in this competitive market of the cable manufacturing industry. In large, to manufacture the pre-determined cable structure at certain cable length through this alternative production line, numerically not only the time required is less three days, also the energy reduction about 3GJ can be achieved.

Keywords: - Discrete event simulation, medium voltage power cable, manufacturing industry

1. Introduction

In the manufacturing industry, the rapid change due to stiff competition among the industries in needing the most economical product arises more intensely than ever. This need includes the great needs for cable in many countries, that is one of the primary resources for the development in infrastructures (Chen et al. 2019). In cable manufacturing industries, the competition in a million of Ringgit Malaysia (RM) bidding tender is contested by few RM. Thus, high competition in the international and domestic market for cables has hammered the defeated companies' growth (Setiawan et al., 2021). Industry players must bid for the lowest price to win the open tender competition. Setiawan et al., (2021) remarked that there has not been much focus on the industry players' efforts in developing the countries' economy based on previous studies under competitive strategy issues. This clearly suggests that cable manufacturing studies should be given more attention. Basically, the manufacturing industries can be classified into Power Cable and Telecommunication Cable manufacturing industries. The interest of this paper is to study whether there is an opportunity to lower costs in Medium Voltage (MV) power cable production line.

Power cable manufacturing production line is an example of a production system that is increasingly becoming more sophisticated and complex (Esmaeilian et al., 2016). Such sophistication and complex production line are often connected with the dense processes in cable manufacturing, involving a vast number of parameters that affect the product output (Abdulkareem et al., 2020). To have a new optimum production line, testing by experimentation requires a setup of multiple new production lines. However, this experimentation cost is not economical for the industry players' immediate return. Moreover, machines for the production line are huge and heavy – adding to the main constraining factor for new production line experimentation. The experimentation is important to design and evaluate a manufacturing system with the prime attempt to lower the production cost, analyse the gathered data through the experimentation production line, and acquire the meaningful insight such as new optimum machine usage schedule. Moreover, Daneshdoost et al., (2022) suggests that by adopting the new schedule, it is possible to decrease the overall production cost and products lead time. However, the possibilities of running actual power cable production line experimentation are required for others alternative because of considering the constraint.

The constraint for the experiment suggests that another economical approach that can replicate the experimentation should be employed. This paper is in favour of the simulation approach since it is much more economical than experimentation approach (Gajsek et al., 2019). Besides, simulation has proven to be a useful tool in various manufacturing applications compared to traditional analytical techniques and simple mathematical models (Reinhardt et al., 2019). Manufacturing systems simulation has proven to be a powerful tool for designing and evaluating a manufacturing system due to its low cost, quick analysis, low risk and providing meaningful insight – thus establishing knowledges of the system components' influence, e.g., machine and process (Mourtzis, 2020). Furthermore, while establishing new knowledge, such an approach would not disturb the actual system (Mourtzis et al., 2014). Though, establishing a simulation study required for sureness in its category, hence a study's category focus needs to be clarified.

Notably, the term simulation covers a wide scope of study that is clearly categorised by stochastic and deterministic systems. As for this paper's simulation study, it investigates stochastic system through replicating experimentation approach for observing the system in a function of time. This stochastic system can be classified in two simulation types – discrete event and continuous (Manuel, 2016). Through a discrete event simulation, the advantage is information gathered can be focused on a selected point in time when certain changes happen in the studied system. This is in line with the paper's interest to obtain the overall system's performance at the simulation end time. Besides, by adopting discrete event simulation, the replicated system can be simulated in several scenarios (Gajsek et al., 2019). In this case, this paper focuses to simulate the replicated system in two scenarios – standard and alternative production line. However, this paper has no interest in collecting information at every point of time, as it focuses on describing continuous simulation type. Thus, due to the study's interest in a discrete event simulation, the information collection is collected between the start and end points. In this paper, start to end process time is known as lead time, is interchangeable used with the word 'time required'. Furthermore, the use of this simulation category is supported by a lot of studies in manufacturing systems.

The current trend of research in discrete event simulation in manufacturing systems covers various product manufacturing systems. In this line, research on specific products includes semiconductor product (Sakr et al., 2019), fixture parts (Kasie & Bright, 2019), gold metal processing (Peña-Graf et al., 2022), extrusion-based additive manufacturing (Bhandari & Lopez-Anido, 2020), and precast component production (Yuan et al., 2020). Besides, discrete event simulation research in manufacturing can be clustered into production system scheduling (Yang et al., 2022), warehouse problem (Ashrafian et al., 2019), and transport manufacturing (Steringer et al., 2019). This literature review evidence that the intense in effectiveness used in the discrete event simulation in the manufacturing system.

Based on the available literature, the current pattern of research in the cable manufacturing system and related studies are classified into five areas. These include, improving cable manufacturing system performance (Daneshdoost et al., 2022); study specific changes of cable structure fabrication (Monssef et al., 2022; Abdulkareem et al., 2020); concentrate on quality control and cable testing (Kong et al., 2022); study on proposing a new design of material, system, and operation (Setiawan et al., 2021); and cable related study of management (Onwuchekwa et al., 2019). Based on the literature, it is found that, currently there is no discrete event simulation study on MV power cable production line, hence this justifies this paper's study. The consideration of the MV manufacturing system in this paper because of the studied system's facilities such as machine and processing time required, are not fully utilized. Therefore, this study is expected to propose a new system which is much more economical in terms of manufacturing cost.

For introductory, this study is interested in MV cable production lines based on the IEC 60502 standard for the maximum system voltage of 7.2kV, 12kV, 21kV, and 36kV. Though, there are other standards for MV cable design, the standard is the most common and acceptable used by international customer's design for MV cable, which includes the local use, i.e., Malaysia. For a short length of cable demand, commonly the quotation for the cable length can be between a few km and up to hundreds of km. Besides, based on a country's power supply needs, the cable structure is customized design based on a standard. MV cables applied for power distribution between an energy generator to sub-stations, transformer, and any application based on the cable maximum system voltage. The cable's designed of external layers are chosen depending on the environment the jacket will be exposed to. For instance, the cable installed in a trunk, it's not required for armour layer. However, for the cable directly installed underground, it's required for armour layer of cable.

By this information, remarked that the cable is customizable at design of cable structure that required machines for each process or layer. The cable manufacturing system's case study used in this paper has an issue with more than one machine for each process in the production line. This is because there is a standard machine used for certain cable size, cable structure, and cable voltage. However, other machines are also applicable for processes in similar production lines. So, in this paper, the first stage is to develop the standard production line based on standard machine usage. Then, based on the standard product line, the alternative production line is developed. Thus, these discrete event simulation models are manipulated in two scenarios, through this paper aiming to determine the optimum production line performance metrics, i.e., electricity consumption and time required. The optimum production line in this case is to propose a production line with less energy usage at the acceptable time required for the proposed cable structure and pre-determine cable length.

2. Simulation

MV cable refers to cable that withstands the voltage range of certain voltage ratings. Manufacturers refer to the voltage rating in the non-uniform range since they focus on the cable that they manufacture. For an appropriate voltage rating guide, cable standard is referred here. According to International Electrotechnical Commission (IEC), MV cable based on the IEC 60502 standard is rated above 1kV up to 100kV, define uniform rate of cable voltage (International Electrotechnical Commission, 2005). American National Standard Institute (ANSI) based on ANSI C84.1-1989 standard definition that the Medium Voltage Cable is within the range of 2400V to 69000V (American National Standards Institute, 1989). Thus, this voltage rating range for MV cables based on maximum voltage system value will be the basis for this paper. Since the complexity of the actual system of MV production line, the system is simplified in such a way that only concerned processes are counted for the system's production line simulation model. Moreover, for costing purposes, testing, and packing processes are excluded in the simulation model. The test is conducted while undergoing the process as well as prior to the manufacturing process to ensure any new material used is in accordance with the referred standard. Therefore, no additional time is required for manufacturing. Besides, energy consumption for the test is too small and can be ignored for energy consumption. Similarly, for the case of the packing process, it is common that the Sales Department excludes any energy consumption and time required for costing from Packing Department. Due to the cable market being so competitive, it is imperative to protect the company's data used in this study. Hence, the company's name, production output, and certain technical details are kept confidential. Besides, the only data which is generated from the company's original data will be displayed in this paper.

2.1 Cable Structure Based for Sequence of Processes

Due to wide cable varieties can be manufactured by the company, this study will only focus on the MV multiple cable types and selected maximum voltage system. Fortunately, through this study, by simulation the modelled production lines allow the replication of actual operation. The simulation is proposed to run only on MV multiple cable types and selected maximum system voltage. The multiple cable types based on core number, XLPE Insulating, PVC Bedding, and PVC Sheathing, with or without steel amour cables. Besides, the cable lengths are pre-determined to set the cables manufacturing completion is proposed. These proposed features detail is shown in Table 1, including cable types, i.e., selected structure layers, core number, cable lengths, and maximum voltage system for each cable modelled for the simulation study.

Table 1. Proposed cable type and pre-determine length

Cab.	V_m	Len.	NC	Scrn.	Armour
1	12kV	19km	1	Cu. Wire	Steel Wire
2	21kV	21km	1	Cu. Tape	−
3	36kV	17km	1	Cu. Wire	−
4	7.2kV	16km	3	Cu. Tape	Steel Wire
5	7.2kV	13km	3	Cu. Tape	Steel Wire
6	12kV	18km	3	Cu. Tape	−

Note: Cab. = Cable; V_m = Maximum System Voltage; Len. = Length; NC = Number of Core; Cu. = Copper; Scrn. = Screening Material; − = Not Applicable; All of these cables' construction: Copper Conductor, Triple Extrusion XLPE; PVC Outer Sheath; For Armoured cables with PVC Bedding and PVC Outer Sheath.

In this paper, the studied MV cables are within the Wm range of 7.2kV and 36kV. Processes in the simulation model are developed based on the structure of a cable. All the processes are mentioned in the following discussion based on the image shown in Fig. 1 below. The structure of these cables is both single core and three cores - the specified commonalities in cable standard design for cable making. The single core structure is applicable to Cable 1, Cable 2, and Cable 5, and triple core structure is for Cable 4, Cable 5, and Cable 6.

The first process in manufacturing a MV cable is conductor fabrication. The conductor reached the factory in a bigger size of wire known as a rod. This rod will be reduced into a standard wire size which is called Drawing process. This is followed by the Stranding Process to strand the wires. The stranding of a certain number of wires by certain wire diameter size sums up the total conductor area size. These conductors are based on wire numbers and wire diameter for a conductor area size as follows: seven wires with 2.14mm wire diameter indicates in this code 7/2.14mm for 25mm² conductor area size; code 19/1.53mm for 35mm²; code 19/2.14mm for 70mm²; 61/2.85mm for 400mm²; 61/3.20mm for 500mm²; and 61/2.25mm for 240mm².

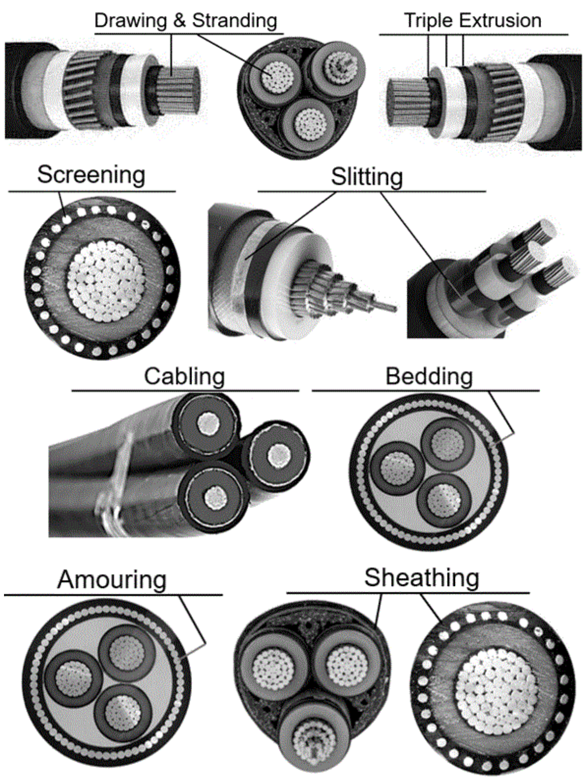


Fig. 1. Cable structure for the studied cable

The third process is a triple extrusion process. This polymer acts as the insulation for the conductor in three layers of polymers. XLPE is the actual insulation for the conductor. However, the first and the third layers made of semi conductive polymer material enforce and serve as a protective layer to the XLPE layer. Hence, all MV cables must be insulated with this triple extrusion. Cable structure design depends on the customers' request based on a particular standard. The customer may request screening layer after the triple extrusion process in either spirally applied copper tape or copper wire. For this layer, the name of the process is Screening, if several copper wires are applied – common for a single core. However, for a three-core cable design, after the insulation, when copper tape is applied, known as Slitting process, then the cable undergoes the cabling process. Later, if a cable does not need any further protective layer, extrusion for outer sheath or Sheathing layer is the next process. However, for a cable that requires a further protective layer, specifically for underground cable, a steel wire layer, i.e., Armouring is applied before the outer sheath layer. Furthermore, a polymer layer cushioning this protective layer must be applied and named as Bedding layer. Hence, for a cable with this protective layer it requires Bedding, Armouring, and Sheathing processes accordingly.

2.2 Modelling with Arena

This section describes the use of discrete event simulation with Arena Software in modelling MV production line system. The model replication is to highlight the significance of a numerical application through a simulation of the system. The explanation on the implementation of simulation models in real-time working of the MV production line system is included to indicate the outcomes of the proposed alternative system. The system's behaviour is easier replicated using the simulation software compared to traditional numerical analysis or experimental approach. The integration of discrete event simulation with the MV production line system's performances focuses on time required and electricity consumption to complete the whole cables proposed in this paper. The integration of the performances depends on the MV production line system's production line flow. In addition, the integration of the model is designed as realistic as possible to assist this study to gain the intended outcome out of the simulation results. The results are expected to assist in decision making in this study in selecting the most optimal condition for the selected performances. It begins with developing models that replicate actual systems for a single cable production line. Then the actual system, i.e., both the standard and alternative, is developed based on this finding and settings. After the simulation result is generated, the data is analysed by comparing the outcome of the standard production flow and the alternative production flow. Briefly, in Arena Software, the model is designed in sequence modules in a flowchart. These modules define the process to be simulated: such as Create, Dispose, Process, Decide, and Record modules. In simulation conceptual design, during the simulation there is the entity that will flow through and serve by these modules. In manufacturing's system, the entity includes parts, sub-components, or from partially complete cable to complete cable.

2.3 Verification of Simulation Model Separately

Before the complete system is modelled, a simple standard flow for each cable is developed to verify the system in a separate single production line. These production line models are simulated unconnected to collect the output from each line model. Based on this line output, it is compared repetitively to meet the correct system's replication. Besides, the output is also verified by the previous production record and production line technical staff. The separated single cable for each cable type is modelled and shown in Fig. 2 for the standard production line, and Fig. 3 for the alternative production line.

2.4 The Complete Simulation Model Development

The main sub model in developing a complete simulation model with Arena Software is a module. Its setup variable and other types of numerical values and expression are related to the whole model. In addition, the models used in this paper are Flowchart Modules and a Data Module to complete the production line system's model. Although these two types of modules are categorized, they are nevertheless interconnected. A new setting in Data Module would change directly or automatically in Flowcharts Models, and vice versa. A Flowcharts Module describes the flow process for the designed model. Create, Dispose, Process, Decide, and Record are the Flowcharts Modules applied on the line model. The entity in this model is referring to the partially complete MV cables, i.e., Cable1 up to Cable6, being manufactured undergoing certain processes. Furthermore, there are processes that need to entertain more than one entity at a time, and the sequence of processes needs to be decided. Therefore, the condition of queueing and deciding to follow or sequence the processes must be set in the model.

Create and Dispose Module establishes the starting and ending points of the model. These modules are created based on the time between these points. The starting point for Create Module named as Copper Rod and Dispose Module at the model end point named as Packing. Record module is placed before the Dispose Module, due to this model the statistic can be recorded before the entity is disposed in Dispose Module. Basically, Record Module collects statistics in the simulation model in various data – time, entity statistics, general observations, and interval statistics, that is important for this study to analysis the data later.

The Process Module in the rectangle shape is the main module compared to the rest. This module is named as process following the process stages in a flowchart; in this case study is the production flow line. Besides, for entity setting and recognise ability purpose, the module's sub name given is Cable1, Cable2, and up to Cable6 that represent the six cables under study. The setting in the module includes a "triangular distribution" of entity distribution flow, and for time the setting is "delay and release". This setting is to set the modules like an actual machine behaviour to manufacture MV cable. For the whole model setup, the sequence of the machines is arranged according to cable's construction, i.e., size and cable type. Furthermore, this whole model setup also replicates an actual production flowline. Then, the electricity consumption is determined in accordance with the time required and cable construction.

This model also requires a decision to be made for two conditions based on entity or cable type. This is due to the following process that depends on the cable construction. Hence, Decide Module in diamond shape is applied in the model. Decide Module shown in Fig. 4 and Fig. 5, is set in the 2-way conditions, implement a basic if-then-else construction, with the entity being directed along either of the two indicated paths based on whether the condition is true or false. For instance, as shown in Fig. 5, after a triple extrusion process, if the following process is screening, then the cable with screening structure will go into the screening process. And the rest of the cables undergo the slitting process. By setting certain conditions before other conditions, this model provides a simplistic flow over the conditions. In the module, the equity equation (==) applies to the condition setting, so that the logical operators operate the appropriate order that equates to the set entity.

As aforementioned, the queue condition must be set to the model, for this reason a Queue Module is one of Data Modules set to the model. A Data Module defines characteristics of various process elements, and the developed flowcharts. Thus, the Queue data module in this paper is derived from the used Process Modules. It is in the form of a spreadsheet that enables the control of queue aspects in the designed model. The control aspect set for this module is "First-in First-out". Hence, the first entity that completes the previous process will be allowed to go first in the following process. For instance, in the case of the design model shown in Fig. 5, the process of Slitting is required by Cable 2, Cable 4, Cable 5, and Cable 6, hence any cable or entity that first completes the previous process, it will be entertained first by the Slitting process. The rest will be entertained by the sequence of which cable comes earlier. The two scenarios are set in the simulation model in this study and are based on the process sequence of the machine used to make the cables. Fig. 4 defining scenario 1 – the standard production line. Fig. 5 defining scenario 2 – the alternative production line.

2.5 Model Validation

The system model and the data generated through the simulated model are validated in two approaches. According to Sargent (2010) there are various approaches that can be done in validating Simulation such as Face Validity and Historical Data Validation. In this paper, the simulation validation is conducted by Face validity approach through asking the technical staff on the production line about the inputs and outputs that should be obtained for the used machine in the model. This technique can be used in determining if the simulation model is logically correct and generates the correct input-output numerical values. Besides, Historical Data Validation is also used for this simulation model, from documents provided by the referred company. In this approach, two parts of the data are clustered – the first part of data is used in the model development and the second part used data generated from the simulated model whether it generated correct valid input-output numerical values. In model development, some available information was added from the company's document, especially production line record that originated from sales document. Once the whole simulation of the production lines is completed, the second part takes place where the additional information is compared and added. The comparison of the gathered information is used to validate the generated data through this study.

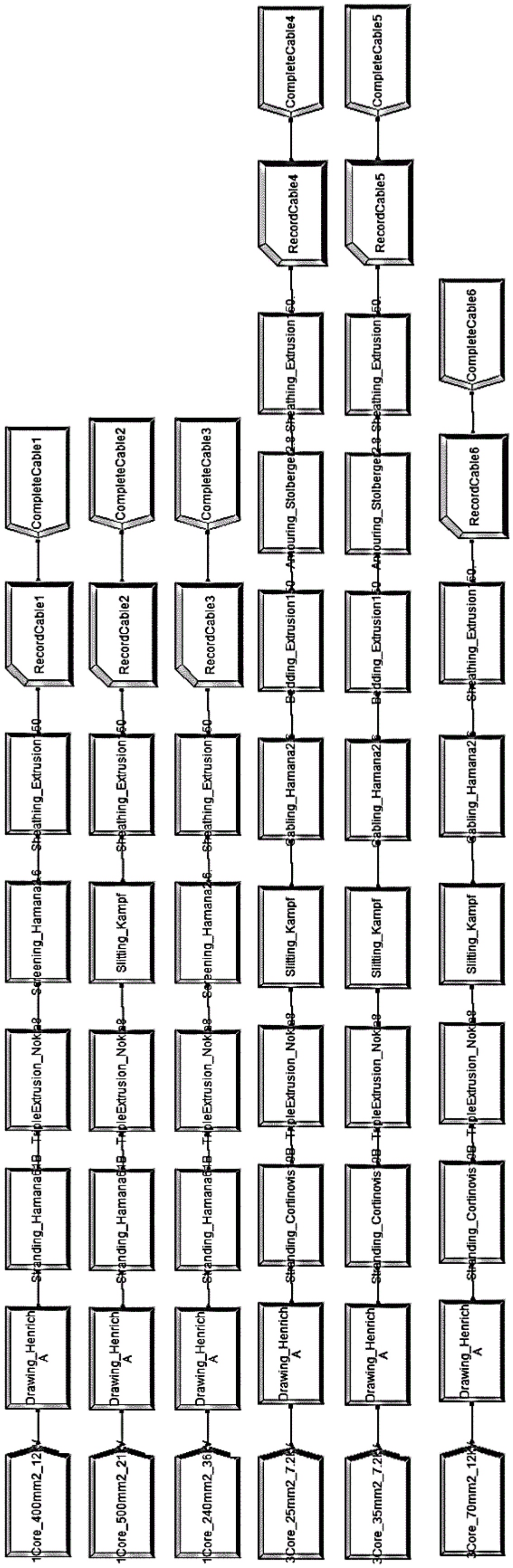


Fig. 2. Standard production flow

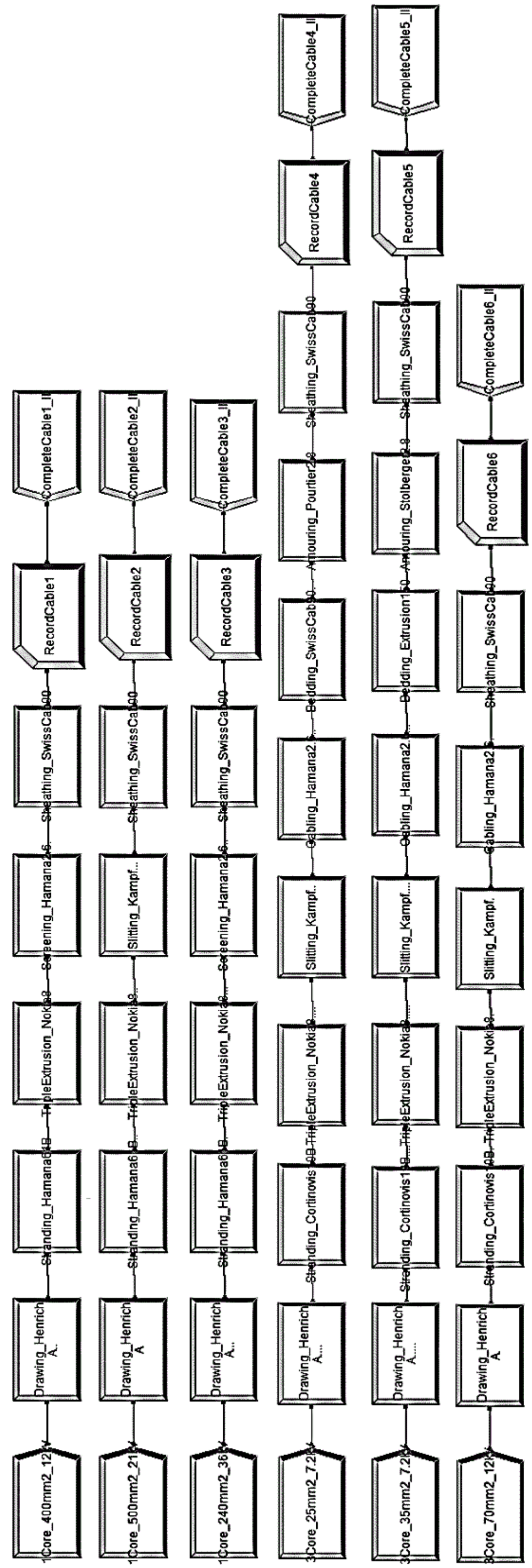


Fig. 3. Alternative production flow

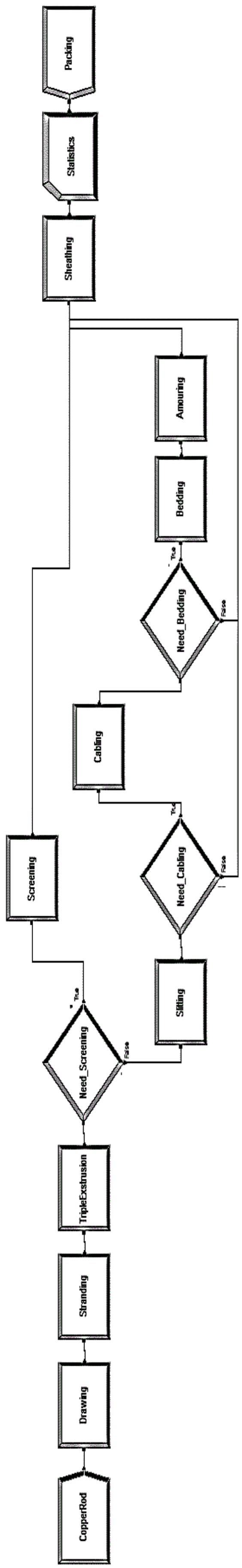


Fig. 4. The complete standard production flow

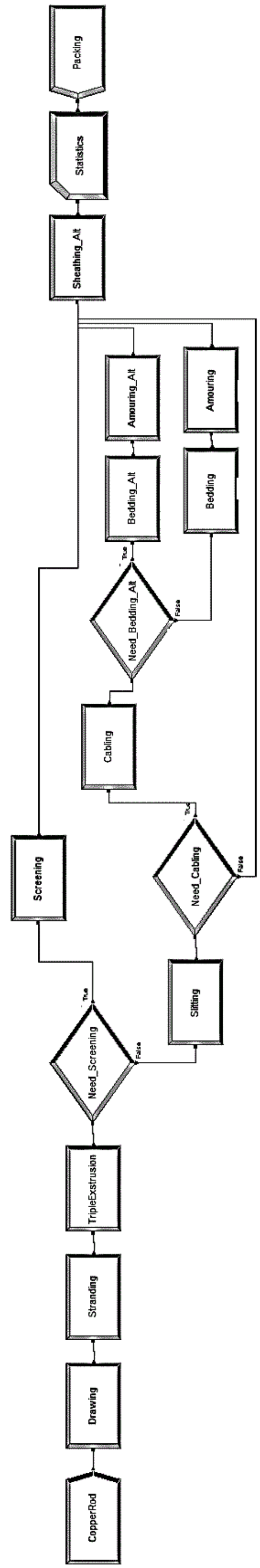


Fig. 5. The complete alternative production flow

3. Result Analysis and Discussion

Table 2. The outcome for each standard machine by process for the referred cable

	Machine/ HR/MC	Drawing	Stranding	Triple Extrusion	Screening	Slitting	Cabling	Bedding	Amouring	Sheathing	Total
Cable 1	Machine	Henrich A	Hamana 61B	Nokia 8	Hamana 2.6	-	-	-	-	Extrusion 150	
	HR (hr)	48.79	40	129.25	76	-	-	-	-	186.96	481
	EC (MJ)	210791	30240	474612	615	-	-	-	-	148074	864332
Cable 2	Machine	Henrich A	Hamana 61B	Nokia 8	-	Kampf	-	-	-	Extrusion 150	
	HR (hr)	65.63	48	124.39	-	0.44	-	-	-	227.03	465.49
	EC (MJ)	283501	36288	456746	-	359	-	-	-	179805	956699
Cable 3	Machine	Henrich A	Hamana 61B	Nokia 8	Hamana 2.6	-	-	-	-	Extrusion 150	
	HR (hr)	32.28	30.22	47.22	68	-	-	-	-	183.78	361.5
	EC (MJ)	139462	22848	173400	145557	-	-	-	-	145557	626824
Cable 4	Machine	Henrich A	Cortinovis 7B	Nokia 8	-	Kampf	Hamana 2.6	Extrusion 150	Stolberger 2.8	Extrusion 150	
	HR (hr)	10.56	9.42	23.39	-	0.15	36.57	120.41	49.23	162.44	412.17
	EC (MJ)	45635	2848	85895	-	38	29623	95368	58663	128650	446720
Cable 5	Machine	Henrich A	Cortinovis 19B	Nokia 8	-	Kampf	Hamana 2.6	Extrusion 150	Stolberger 2.8	Extrusion 150	
	HR (hr)	17.42	9.45	20.06	-	0.16	29.71	106.12	40	136.84	359.76
	EC (MJ)	75264	9360	73667	-	39	24069	84049	47664	108379	422491
Cable 6	Machine	Henrich A	Cortinovis 19B	Nokia 8	-	Kampf	Hamana 2.6	-	-	Extrusion 150	
	HR (hr)	32.26	12.52	35.71	-	0.21	41.14	-	-	195.12	316.96
	EC (MJ)	139349	12397	131143	-	52	33326	-	-	154537	470804

Remarks: hr = Hour Required; EC = Energy Consumption; hr = hour; MJ = Mega Jould.

Table 3. The performance and outcome for each alternative machine by process for the referred cable

	Machine/ HR/MC	Drawing	Stranding	Triple Extrusion	Screening	Slitting	Cabling	Bedding	Amouring	Sheathing	ER (%)/ Total
Cable 1	Machine	Henrich A	Hamana 61B	Nokia 8	Hamana 2.6	-	-	-	-	SwissCab 90	14.15%
	HR (hr)	48.79	40	129.25	76	-	-	-	-	28.84	322.88
	EC (MJ)	210791	30240	474612	615	-	-	-	-	17131	733389
Cable 2	Machine	Henrich A	Hamana 61B	Nokia 8	-	Kampf	-	-	-	SwissCab 90	12.68%
	HR (hr)	65.63	48	124.39	-	0.44	-	-	-	98.46	336.92
	EC (MJ)	283501	36288	456746	-	359	-	-	-	58483	835377
Cable 3	Machine	Henrich A	Hamana 61B	Nokia 8	Hamana 2.6	-	-	-	-	SwissCab 90	15.92%
	HR (hr)	32.28	30.22	47.22	68	-	-	-	-	101.32	279.04
	EC (MJ)	139462	22848	173400	145557	-	-	-	-	450971	932238
Cable 4	Machine	Henrich A	Cortinovis 7B	Nokia 8	-	Kampf	Hamana 2.6	SwissCab 90	Pourtier 2.8	SwissCab 90	18.17%
	HR (hr)	10.56	9.42	23.39	-	0.15	36.57	146.76	68.57	189.33	484.75
	EC (MJ)	45635	2848	85895	-	38	29623	87177	50359	112461	414036
Cable 5	Machine	Henrich A	Cortinovis 19B	Nokia 8	-	Kampf	Hamana 2.6	Extrusion 150	Stolberger 2.8	SwissCab 90	16.02%
	HR (hr)	17.42	9.45	20.06	-	0.16	29.71	106.12	40	210.98	433.9
	EC (MJ)	75264	9360	73667	-	39	24069	84049	47664	125321	439433
Cable 6	Machine	Henrich A	Cortinovis 19B	Nokia 8	-	Kampf	Hamana 2.6	-	-	SwissCab 90	13.97%
	HR (hr)	32.26	12.52	35.71	-	0.21	41.14	-	-	149.4	271.24
	EC (MJ)	139349	12397	131143	-	52	33326	-	-	88746	405013

Remarks: hr = Hour Required; EC = Energy Consumption; hr = hour; MJ = Mega Jould; ER= Energy Reduction Compared to Standard Production Line (%).

3.1 Overall Production Lines Performance

Energy prices are getting higher due to the increased energy demand and decreasing energy sources. Thus, a strategy that can reduce energy consumption is imperative. This study is in line with this purpose as a possible solution to reduce the overall industry production is proposed. It needs to be pointed out that when energy consumption is reduced, it is expected that the time required will increase slightly in manufacturing a product. Thus, the small increase in time should be reasonable and acceptable to industry.

Table 4. Comparison of overall performance parameter

Production Line	Time Required (hr)	Energy Consumption (MJ)
Standard	2708.5	3787870
Alternative	2619.6	3759486

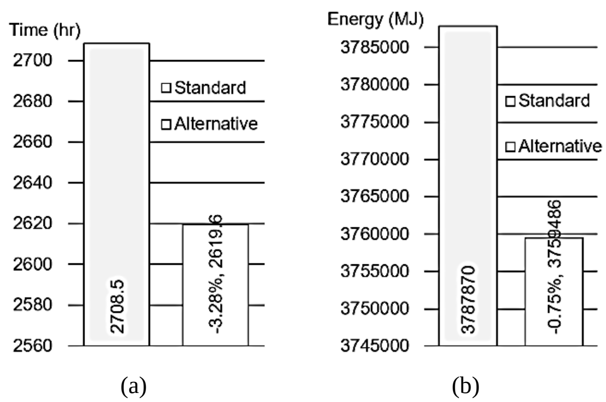


Fig. 6. Overall (a) time and (b) electricity consumption for standard and alternative production lines

Based on the simulation model, each time required can be obtained from the process modules. By the value, the electricity consumption is determined. The total or overall value is gained from the record module located in the flowchart production line model. These values are tabled in Table 2 for the standard production line and Table 3 for the alternative production line. Because of the primary objective of this paper is on the overall energy consumption and time required for the pre-determined cables and cables' length, hence the summary is shown in Table 4. Furthermore, Fig. 6 shows the comparison of Alternative and Standard Production Line. Fortunately, the result shows a reduction in time for an alternative production line of about 88.9 hours or 3.28%, in parallel with the reduction of electricity consumption recorded at 28384MJ or 0.75%.

3.2 Analysis of Individual Machine Performance

The production line performance metrics are arranged as in Fig. 8 and Fig. 7 for comparing both standard production line and alternative production line to visualize the improvement. Generally, the production line performance metrics, i.e., time required, and energy consumption numerical pattern approved that both are decreased in alternative production line. Besides, Fig. 7 and Fig. 8 show how reducing the time on machines used will affect the productions overall time required. Instead, higher energy consumption on certain machines will not translate to better performance, i.e., shorter time required.

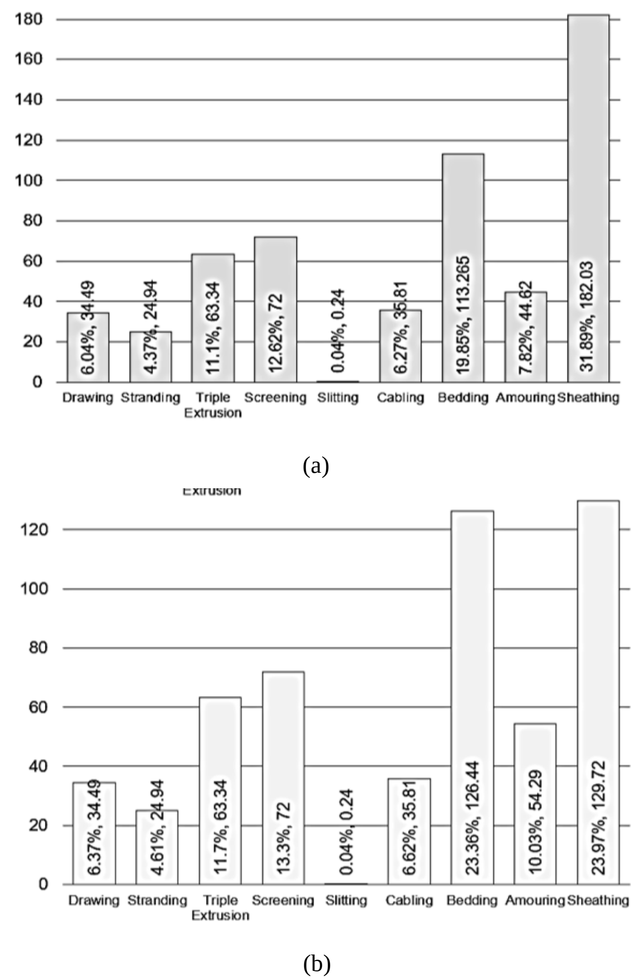
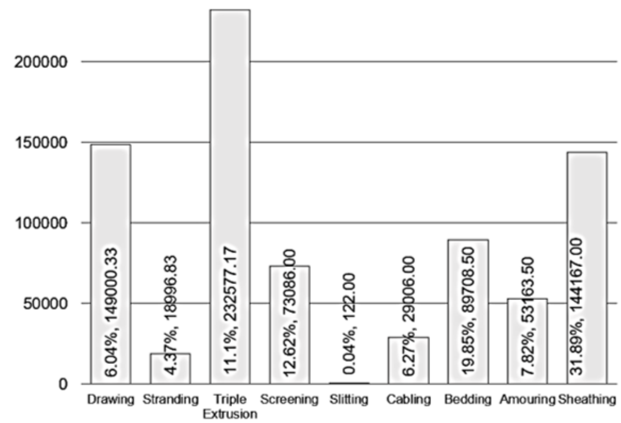
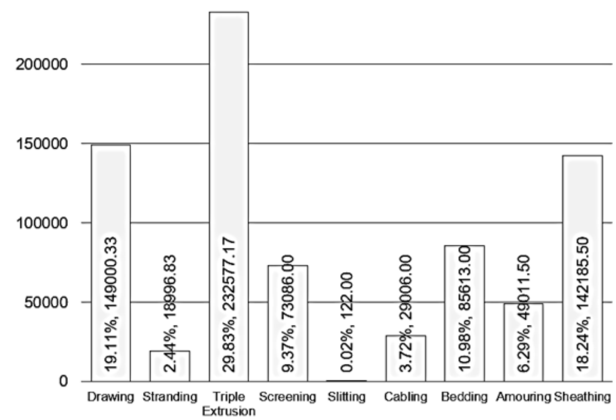


Fig. 7. Average value of time required (Hours) and percentage (%) for (a) standard production line, (b) alternative production line

The production line performance metrics are arranged as in Fig. 8 and Fig. 7 for comparing both standard production line and alternative production line to visualize the improvement. Generally, the production line performance metrics, i.e., time required, and energy consumption numerical pattern approved that both are decreased in alternative production line. Besides, Fig. 7 and Fig. 8 show how reducing the time on machines used will affect the productions overall time required. Instead, higher energy consumption on certain machines will not translate to better performance, i.e., shorter time required.



(a)



(b)

Fig. 8. Average value of energy consumption (MJ) and percentage (%) for (a) standard production line, (b) alternative production line

These outcomes show the performance metrics setting for the machines used to process the cables play a fundamental role. Though, few machines are alternately increased in one performance metric still the other performance metrics is decreased. Ultimately, the total value for both performance metrics is reduced.

3.3 Productivity of Production Line

Capacity of producing or productivity in the production line is shown in Table 5. The table shows the significant value for comparison of the time required and energy consumption which can be saved through the alternative production line. Through this study, it is shown that the available alternative resources are being wasted in the production line and consequently the industry is running at less efficient and costly compared to the alternative production line. It is due to the insufficient usage of the available resources, i.e., machines. For these reasons, certain time delays usually appear in the production system which in turn affect the energy consumption and time required to produce the cables. Besides, the result also disclosed the potential changes were made in production line, the production still can reduce the energy consumption cost and at lower time required. This eventually offers chances to compete better in this market. In addition, there is a significant reduction in percentage of the sheathing and amouring process of alternative production line. It shows 1 to 6 percent reduction or in value 45 hours and 8300 MJ.

Table 5. The significant value for individual machine energy consumption and time required

Production Line	Cable No. Process (Machine)	Time Require -ed (hr) with %	Process (Machine)	Energy Consump - tion (MJ) with %
Standard	Cable 6 Sheathing (Extrusion1 50)	195.12; 61.6%	Cable 4 Amouring (Stol-berger 2.8)	58663; 13.1%
Alternative	Cable 6 Sheathing (Swiss Cab 90)	149.40; 55.1%	Cable 4 Amouring (Pourtier 2.8)	50359; 12.2%

3.4 Theoretical and Practical Consequences

In this paper, the system is numerically oriented and approachable to facilitate the sensitive for market competition and the applicable as production line routine for future usage. For competitiveness issue, the studied production line is forced to change manufacturing strategies now and then because of the changes in the market economy. By numerical value, the sensitivity of the changes in the production line can be observed directly. Forecasting the correct numerical value in the production line is a main challenge because of the relentless numerical false value as it involved monetary value. Therefore, by involving the industry technical staff in this analysis it solved this false value issue. Through this study, which begins with theoretical work by computer numerical analysis, i.e., simulation, it is believed applicable for routine in the production line. Although simulation works via soft computing, it imitates the real-world processes such as in this production line. This study allows technical production staff to take part in evaluating the processes closely in a controlled environment. This helps management and technical production staff to make changes in production line operation to gain better performance metrics in the future. Besides, the simulation work can be applied as a part of the work in managing machine usability. This shall help the management to make better choices and the usage to build more simulation after this study.

4. Conclusion

Based on the comparison of the standard and alternative production flow of overall electricity consumption, it can be concluded that the better solution is on the alternative production line. This study positively outstrips the desired aim – to determine the optimum production line performance metrics and propose a lesser energy usage at accepted production line. The electricity consumption for alternative production is less at 28384MJ than standard production energy consumption. Besides, the time required for both productions was also observed, and signified substantial results. The simulation result helps to determine that the overall time for production line takes 2709 hours for the standard line, and this outstrips by alternative line by 2617 hours for the overall time. This is about 89hr or about 3 days of production time reduction.

The proposed alternative production flow is obviously more economical, and less time is required to manufacture the selected cable, which is a huge economic value for this manufacturer. Besides, this is a promising win for a bidding tender in marketing MV cables. Through extensive evaluation using real data, the proposed alternative production line is indeed effective in reducing electricity consumption and lessening the production time. In this paper energy consumption is reduced in the production line that consists of multiple machines. While it is expected that the total production time will increase when the overall electricity consumption decreases, such was not the case for this study. The overall production time required was noted to have a significant decrease in total.

As for future investigation, there are several interesting questions that have emerged. First, to extend the results studied in this paper, it is suggested to incorporate more complex and general problem setting such as all machines having various release times; includes periodical schedule counting machine maintenance time and considering the required number of operators. As such, a more concrete and comprehensive solution that can minimize the production cost can be realised.

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