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Application of Karnaugh Map Methods to Bill of Engineering Measurement and Evaluation in Industrial Process

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ABSTRACT : *The aim of preparing BEME is to quantify work items for pricing, provide a priced bill for evaluating regularly or periodically executed work to control the project and prepare interim and final payment certificates. It also serves as a document for dispute settlement regarding compensation. The significance of BEME includes providing rates and prices for negotiating variation and extra work, comparing vendor pricing during the tendering process, estimating the project cost, and providing information for planning and budgeting. Most studies have been conducted on engineering management evaluation with a cost-minimization approach, using the Karnaugh map optimization technique. The K-map optimization technique has proven effective in reducing components performing similar functions during industrial processes to optimize production materials, production, and profit maximization. The paper has considered the corking, stamping, and pillarization process of an industrial brewery, describing and establishing the sensor components of the system in a K-map study for optimization based on their path sequence. The optimized path sequence was used to create a call-up table for determining the number of sensor components with similar functionalities. A BEME was performed to compare the cost of the original and optimized systems for two different manufacturing brands, Festo and Allen Bradley, in USD. The BEME revealed that the cost of the industrial setting using the optimized approach was lower.*

KEYWORDS: Karnaugh map, BEME, Path sequence, Optimized Sequence

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I. INTRODUCTION

The BEME which can also be referred to as the bill, is a measurement and evaluation tool which is used as means of assessing and valuing the cost of construction project/works and comprising of the works' materials, equipment's, labour and any other resource needed for the satisfactory completion of the works unlike the bill of quantities (BOQ) which is usually for building projects such as residential, schools, recreational buildings, hospitals and industrial building works, (Moses, 2021). The BEME is basically an evaluation tool for civil engineering works like roads, retaining walls, drainages, bridges, culverts, dams and railways amongst others. The purpose for BEME preparation is to provide the quantities of the work items for pricing to make available a priced bill to be used for evaluation of work executed routinely or periodically for the purpose of control of the project and as a guard for preparing interim and final payment certificates during work-in progress and at completion of project. It also serves the purpose dispute settlement document regarding compensation. In the focus of engineering management, (Coates et al, 2004) wrote General and Industrial Management in which management was described as a process consisting of planning, organization, coordinating, directing and controlling, Engineering management only emerged as a discipline in its own right in the latter part of the 20th century. As such, various interpretations of the term engineering management have emerged and, consequently, numerous definitions exist. Although engineering management has started to attain the status of a recognized discipline, research efforts in this field have been described as fragmented and uncoordinated (Lock 1993). Furthermore, Lock noted that in the current climate of rapid technological change and an intensively competitive global environment there is a demand for a renewed emphasis on effective engineering management and a re-evaluation of traditional attitudes and approaches. This point is echoed by Thamhain (1992), who recognized that today's engineering environment is more challenging than ever before due to increased technical complexity, and interdependency of technical tasks.

The main objective of every industrial setting is to reduce cost of production and maximize profit. Cost minimization in any industrial settings follows the reduction in the cost of industrial components. According to Santos (2017), the cost of production can be reduced by reducing the component in the system. Most optimization engineers have sought ways to reduce complex systems by reducing its component by making them as simple as possible. Santos asserts that reducing the complexity of a system can help reduce cost of components and also increase profit maximization. Ferreira and Santos (2015) considered sensors and components in an industrial and pneumatic actuator as Boolean units and that their control and sensor actions can be represented using Boolean algebras and the overall industrial process can be expressed in a Boolean logic expression

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II. METHODOLOGY

A general method for simplification of Boolean algebra and logics has always been the Karnaugh map method. The approach of Karnaugh mapping will be implemented in this study which will help reduce the steps complexity and procedures involved in the control of electro pneumatic and hydraulic operations described in previous sections, K-map will be used as a technique to minimize the ON/OFF control and sensor actions (pneumatic or electro pneumatic) circuits combined or in sequential format. In pneumatics, the complexity arises when one needs to automate sequential processes. In this situation, control of the power parts (cylinder) not only rests on the state of present information but also from knowledge of past actions. In practice, ensuring a collection of sequential movements in an automatic cycle is to trigger a collection of mechanical actuators based in a set of equations that are executed to ensure the realization of the desired control sequence to perform a task. The command equations of the cylinders that will allow its movement (forward and backward) are functions of two kinds of variables, identifying variables cylinder positioning and memory variables (Santos, 2017).

A. KARNAUGH MAP APPROACH FOR OPTIMIZATION

The application of Karnaugh maps to systems are used mainly to simplifying and minimizing Boolean function. In addition, the implementations of the Karnaugh maps method help solve industrial control problems. This method can be used to design and build ON/OFF control systems having as command power either compressed air or electricity, (Santos, 2017).

However, instead of being organized into columns and rows like a truth table, the Karnaugh map is an array of squares (or cells) in which each square represents a binary value of the input variables. The squares are arranged in a way so that simplification of given expression is simply a matter of grouping the squares. Karnaugh maps can be used for expression with two, three, four, and five variable Karnaugh maps to illustrate the principles (Somani, 2014). The number of squares in a Karnaugh map is equal to the total number of possible input variable combinations (as is the number of rows in a truth table). For two variables, the number of square is 2^2 = 4, for three variables, the number of squares is 2^3 = 8 and for four variables, the number of squares is 2^3 = 16. The K-map for three variable, function A, B and C, can be seen in Fig.1

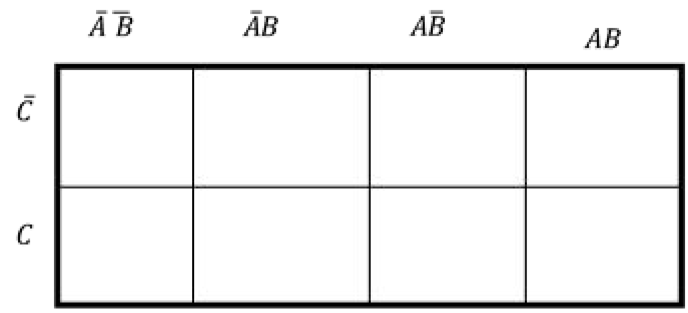

Fig. 1: K-map for three variable

A minimization model used in (Santos, 2017) was used to solve industrial problems of reducing cost and improving system efficiency. Any industrial control process which uses this approach will have implemented optimization in its process. The approach to be implemented organize the K-map table to be in this form (Fig. 2) for a three variable input, where the line above the table negate each of the variables

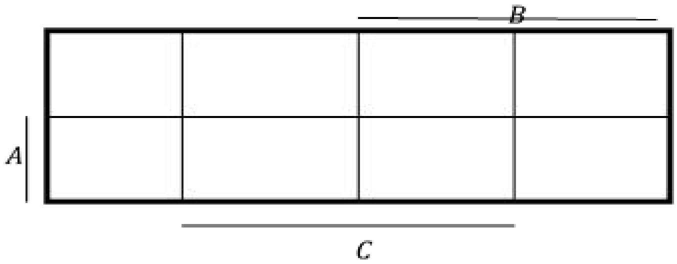

Fig. 2: Optimization form of the K-map table

a. Sequential movement in automation cycle

Sequential movements in automatic cycle describe a set of equations that once implemented in reality, guarantees the realization of the desired sequence. So, the goal will be to build a matrix taking into account the correspondence between the states of the primary variables according to implementation by (Santos, 2017), end-of-stroke sensors, represented by lowercase letters a_0, a_1 and memories in sequential circuits $\bar{x}$, x. The distribution valves are tagged using capital letters, A_1 as Extract and A_0 as Retract see (Fig. 3).

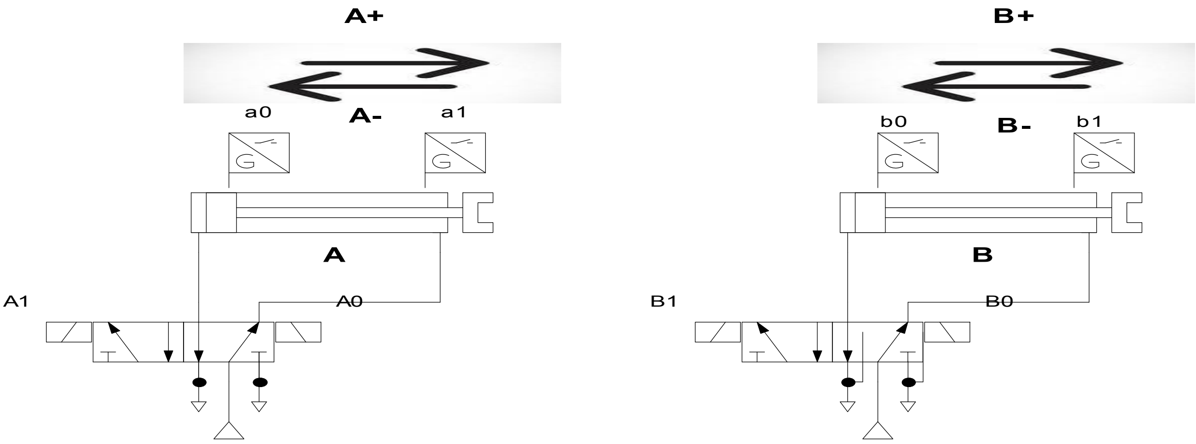

Fig. 3: Representation of variables for sequential movement of cylinders

Table 2 shows a summary of the initial and final position of the proximity sensors for each sequential valve control, the movement from A+→A- and A-→A+ will be sensed by proximity sensors a_1 and a_0 at the final and initial position respectively, while the movement from B+→B- and B-→B+ will be sensed by proximity sensors b_1 and b_0 at the final and initial position respectively.

Table 2: Relationship between variables and sequences

Proximity sensor (Position at 0)	Valve control	Proximity sensor (Position at 1)
$a_0.b_0$	$A^+ \rightarrow A_1$	$a_1 . b_0$
$a_1.b_0$	$B^+ \rightarrow B_1$	$a_1 . b_1$
$a_1.b_1$	$B^- \rightarrow B_0$	$a_1 . b_0$
$a_1.b_0$	$A^- \rightarrow A_0$	$a_0 . b_0$

The Karnaugh mapping method for optimization is well suited for circuit design of all sizes including compound circuits not implementable by the Cascade method and others. Furthermore, the method leads to a minimized set of logic equations (Somani, 2014). The essential steps and systematic approach of Karnaugh mapping method for pneumatic and electrical control circuit design are, Development of the Karnaugh map, plotting of cycle path based on a given set of rules, Minimization of logic equation obtained from the developed K-map based on mirroring rules. So, for better explanation on the operation of the K-map method can be done using the printing process that follows the sequence as shown in $M1^{+}\backslash M2^{+}\backslash M2^{-}\backslash M1^{-}\backslash M3^{+}\backslash M3^{-}$ (Fig. 4).

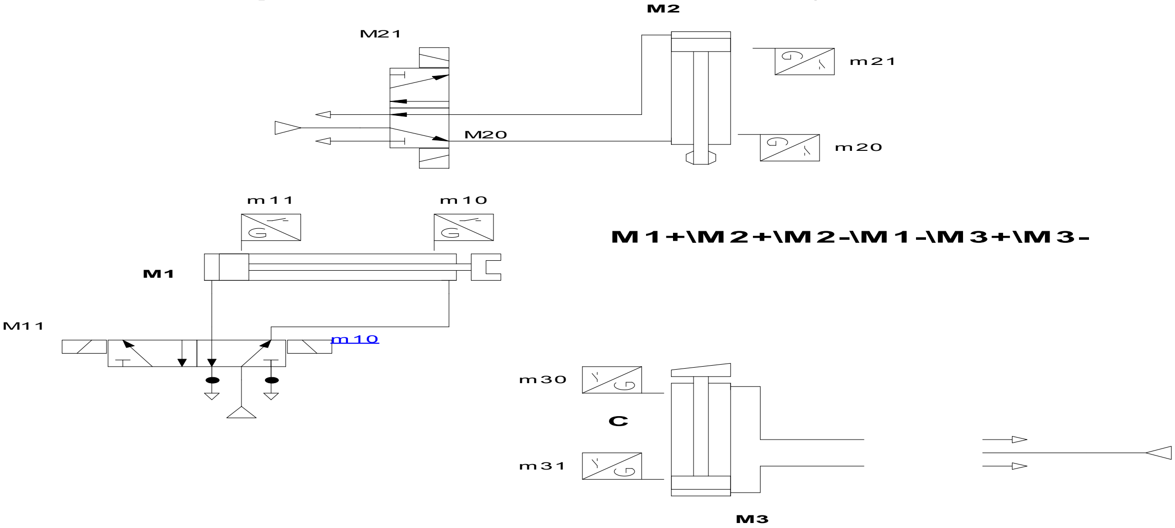

Fig. 4: Representation of the printing process on automation studio

Fig.4 explains the motion sequence of the three pneumatic cylinders in the printing system, the plot represents the sequence $M1^{+}\backslash M2^{+}\backslash M2^{-}\backslash M1^{-}\backslash M3^{+}\backslash M3^{-}$ in Fig. 3.81. The column represents the sensors that are actuated at the respective extended position of the cylinders m1, m3 and the horizontal lines the extreme position of the cylinder M2 (Fig. 5). To start plotting cycle path in the Karnaugh Matrix it is necessary to ensure that the initial position of the cylinders may be described in the upper left corner of the matrix (position $m1_0m2_0\ m3_0$, Fig. 6). The size of the basic matrix for the sequence above will be 2^n cells were n is the number of cylinder, assuming that each cylinder has only two Proximity sensors, (Santos, 2017).

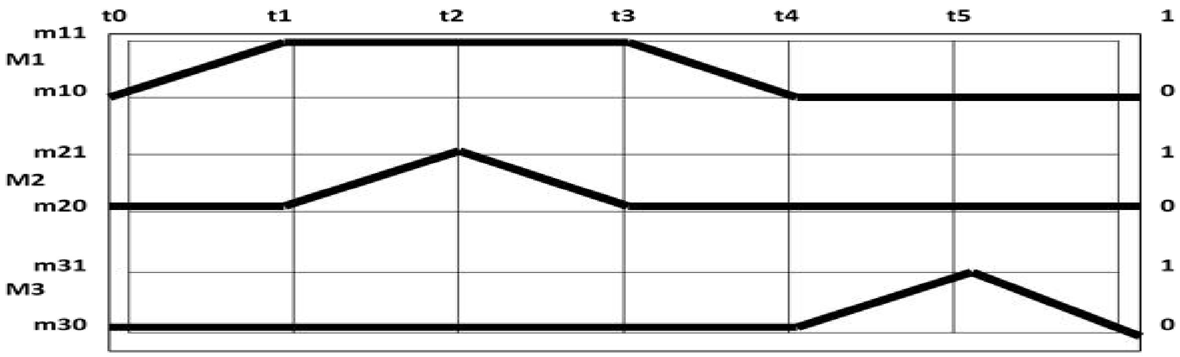

Fig. 5: Displacement-step diagram of the 3 cylinders

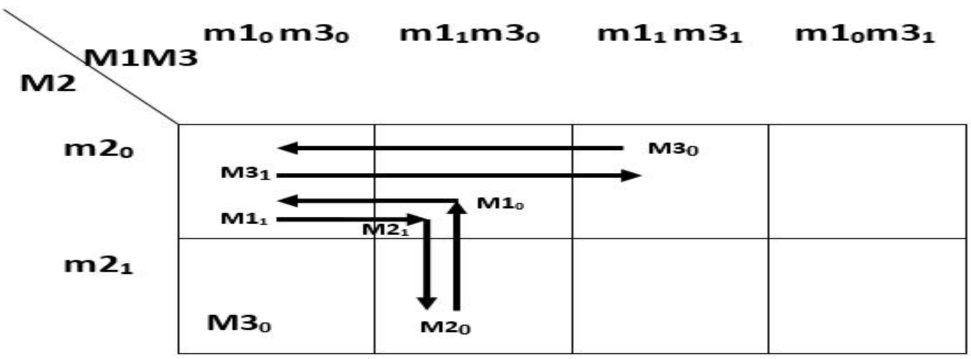

Fig. 6: Karnaugh maps for the printing sequence for the 3 cylinders (M1, M2, and M3), not optimized

B. OPTIMIZATION OF BREWERY (CASE STUDY) INDUSTRIAL AUTOMATED PROCESS

a. Corking, Stamping and Palletizing Process

The corking, stamping and palletizing stages of the industrial automation process can be optimized using Karnaugh map and sequential movement in automation cycle, this section presents the truth table alongside the Karnaugh map of the industrial process and lastly the optimization plan. The corking, stamping and palletizing stages previously described in this work follows the following sequential movement as shown below, each step in the sequence has a variable requiring a memory between present and past states. The sequence also shows that after the first two steps in the sequence, the three cylinders perform simultaneous action ending an action and immediately starting it again.

$$\backslash\, C+\backslash\, C-S+\backslash\, C+S-P+\backslash\, C-S+P-\backslash\, C+S-P+\backslash\, C-S+P-\backslash\, C+S-P+\backslash\, C-S+P-\backslash\, C+S-P+\backslash\, C-P-$$

The sequence explains the actions of 3 cylinders with the first set of the sequence showing the corking action of the corking cylinder, the second set shows the next action with retraction of the corking cylinder and a simultaneous extraction of the stamping cylinder, the next set shows a simultaneous action of the three cylinders with the corking and palletizing cylinders extraction and the stamping cylinder retraction. The Representation of a pneumatic/Hydraulic cycle is shown in Fig. 7, where the stroke sensors c_0, s_0 and p_0 are the piston retraction stroke sensors and c_1, s_1 and p_1 are the piston extraction stroke sensors.

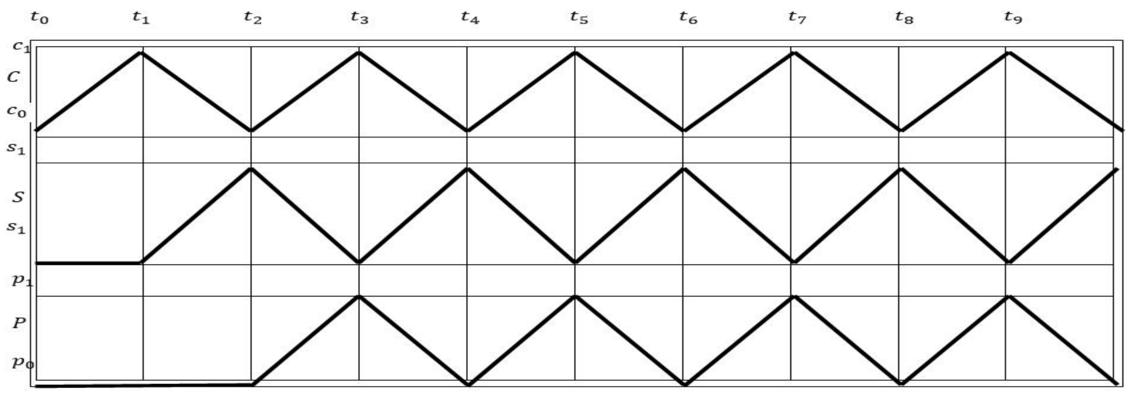

Fig. 7: Displacement-step diagram for corking, stamping and palletizing cylinder actions

The Karnaugh map for the sequence cycle is presented in Fig. 8. The size of the basic matrix for the sequence above will be 2^n cells were n is the number of cylinder, assuming that each cylinder has only two end of-stroke sensors.

The map in Fig. 8 shows the repetition of the actions in each step included in the sequence. For proper optimization there is need to follow the optimization steps described previously, to achieve this, the memory and not memory sensors will be implemented on the table. The rules forbids a cell to be occupied twice, so the unavailability of a cell require a mirror duplication of the Karnaugh table vertically (Y memory) for movements involving cylinder C and P and horizontally (X memory) for movements involving cylinder S, this is described in the next step pointed to by the arrow.

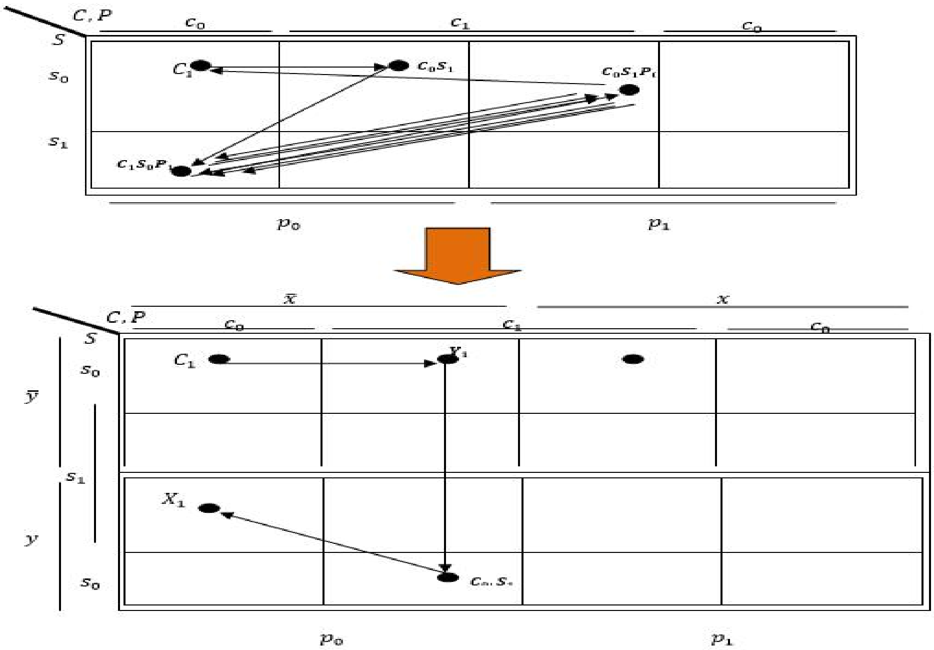

Fig. 8: The Karnaugh map for the sequence cycle

It is seen from Fig.8 that the action $C_0.S_1$ is not allowed back into cell $c_0.s_0.\bar{y}$, a mirror of the table is taken vertically below and the mirror cell $c_0.s_1.y$ is used as a return cell for the action $C_0.S_1$ Further mirror duplication will occur at the fourth step extraction sequence involving cylinder C and P, for accuracy sake it is better to the mirrors before the Karnaugh mapping so as to ensure accuracy in the mapping. The total K-mapping system requires a vertical mirror flip twice and a horizontal mirror flip twice too, Fig.9 describes the overall corking, stamping and palletizing system for a single crate in K-mapping, where $X\ and\ Y$ describes the memory states. It is important to know that the initial K-map has been flipped twice both horizontally and vertically so as to avoid reoccurrence of an action in a cell.

Table 3 presents the original and optimized path sequence using Karnaugh map for the corking, stamping and palletizing proces.

Table 3: Original and Optimized Path Sequence

Original Path Sequence	Optimized Path Sequence
$C_1 = c_os_0p_0.\overline{c_1}\ \overline{s_1}\ \overline{p_1}.\ \bar{x}\bar{y} + c_os_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ xy + c_os_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ \bar{x}\bar{y} + c_os_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ xy + c_os_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\bar{x}\bar{y}$	$C_1 = p_0\bar{x}\bar{y} + c_0p_0\bar{y} + c_0\bar{x}\bar{y} + c_0p_0y + c_0xy$
$C_0 = c_1s_0p_0.\overline{c_0}\ \overline{s_1}\ \overline{p_1}.\ \bar{x}y + c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ x\bar{y} + c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ \bar{x}y + c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ x\bar{y} + c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ \bar{x}\bar{y}$	$C_0 = p_0\bar{x}y + c_1\bar{x}y + x\bar{y} + c_1s_0\bar{x} + s_0x$
$S_1 = c_1s_0p_0.\overline{c_0}\ \overline{s_1}\ \overline{p_1}.\ \bar{x}y + c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ x\bar{y} + c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ \bar{x}y + c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ x\bar{y}$	$S_1 = s_0p_1\bar{x}y + s_0p_0\bar{x}\bar{y} + c_1x\bar{y} + x\bar{y}$
$S_0 = c_0s_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ xy + c_0s_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ \bar{x}\bar{y} + c_0s_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ xy + c_0s_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ \bar{x}\bar{y}$	$S_0 = s_1p_0\bar{x}\bar{y} + p_0\bar{x}\bar{y} + c_0xy + p_0xy$
$P_1 = c_0s_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ xy + c_0s_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ \bar{x}\bar{y} + c_0s_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ xy + c_0s_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ \bar{x}\bar{y}$	$P_1 = p_0\bar{x}\bar{y} + c_0\bar{x}\bar{y} + p_0s_1y + xy$
$P_0 =\ c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ x\bar{y} + c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ \bar{x}y + c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ x\bar{y} + c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ \bar{x}y$	$P_0 = c_1x\bar{y} + c_1x + p_1s_0\bar{x}y$
$Y_1 = c_1s_0p_0.\overline{c_0}\ \overline{s_1}\ \overline{p_1}.\ \bar{x}\bar{y} + c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\bar{x}\bar{y}$	$Y_1 = s_0p_0\bar{y} + c_1s_0\bar{x}$
$Y_0 = c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ xy + c_1s_0p_1.\overline{c_0}\ \overline{s_1}\ \overline{p_0}.\ xy$	$Y_0 = s_0c_1x + p_1s_0y$
$X_1 = c_0s_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ x\bar{y} + c_0s_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ x\bar{y}$	$X_1 = s_1c_0\bar{y} + c_0p_0\bar{y}$
$X_0 = c_0s_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ \bar{x}y + c_0s_1p_0.\overline{c_1}\ \overline{s_0}\ \overline{p_1}.\ \bar{x}y$	$X_0 = p_0s_1c_0y + c_0p_0y$

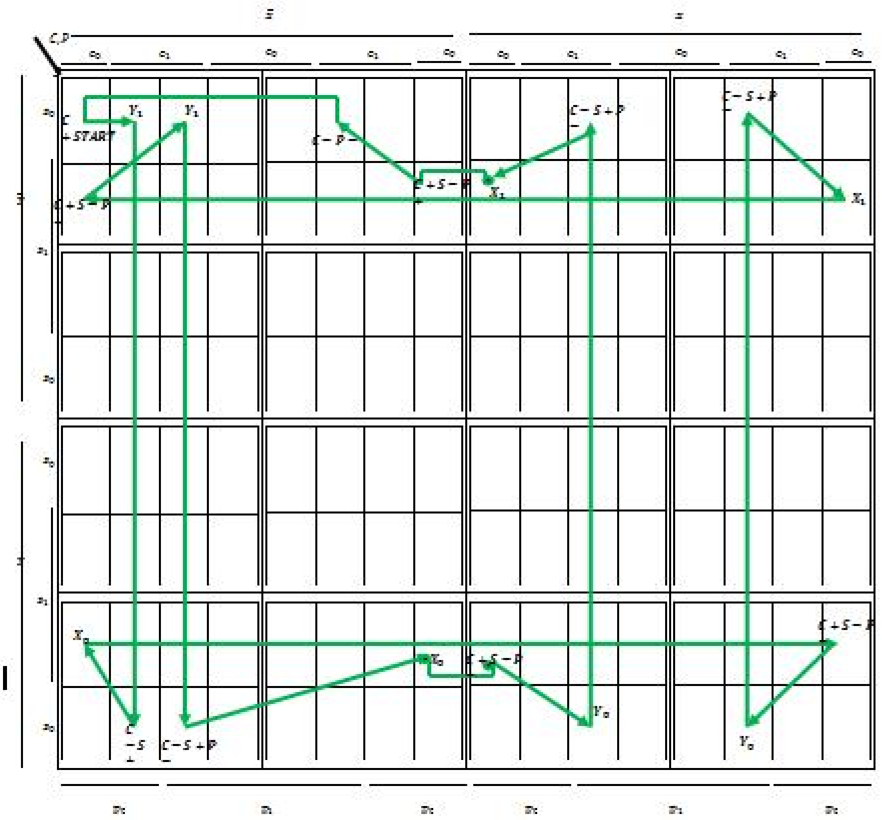

Fig. 9: K-map for corking, stamping and palletizing actions of the industrial automation process

III. RESULTS AND DISCUSSION

A. BILL OF ENGINEERING MANAGEMENT AND OPTIMIZATION EVALUATION

a. Comparison Original and Optimized System (Sensor Call Up)

Sensor call up describes the number of times a proximity sensor is called up during the industrial operation sequence. Table 4 describes the available sensors to initiate the industrial action using the available cylinders. The optimized system using Karnaugh map reduces the sensor call up by picking up usage of sensors for multi-actions, thereby reducing the number of sensors that will be called up to the number of times a particular sensor will be called up. The table shows that in the optimized system, sensor c0 was called up 4 times instead of 18 times as indicated by the original system. Sensor **s1** was called up 4 times instead of 16 times as seen from the original system.

Table 4: Table showing number of sensor call up for stacking and lifting system

Number of times sensor is called up (Corking, stamping and palletizing system)		
Sensor	Original system	Optimized System
Sensor c0	18	4(c0,s1,p1)
Sensor c1	17	2(c1,s0,p0)
Sensor s0	18	9(s0,c1,p0)
Sensor s1	16	4(s1,c0,p1)
Sensor p0	20	14(p0,s0,c1)
Sensor p1	14	3(p1,s1,c0)

b. Cmponent management and evaluation

One of the advantages of optimization is its ability to reduce the number of components used in any system and also the cost of implementation. There is need to compare the number of Components. Table 5 shows that after optimization, there is reduction in the number of components from the original system to the optimized system, in a similar fashion there will be a reduction in the cost of implementation of the optimized system. The table show the list of materials required for implementation of the industrial brewery system for corking, stamping, palletizing, lifting and stacking. The list of materials contains all mechanical and electrical control components, together with the control unit (PLC). The price list for each and total component for a Festo and an Allen Bradley product are specified in USD for each of the original and optimized system. The total cost of the system has been highlighted at the table bottom.

Table 5: Bill of engineering management and evaluation table for corking, stamping and palletizing system

Corking, Stamping and Palletizing								
	Quantity		Cost/Unit (US Dollar) manufacturer(module not specified)		Total cost			
Component Name	Original System	Optimized System	Festo	Allen Bradley	Original System		Optimized System	
					Festo	Allen Bradley	Festo	Allen Bradley
Automation PLC	6	3	30.56	33.5	183.36	201.36	91.68	100.5
Double Acting Hydraulic Cylinder	1	1	76.6	64.99	76.6	64.99	76.6	64.99
Double acting Pneumatic cylinder	2	2	102.8	109.00	205.6	218	205.6	218
Normally Closed Contact	43	27	12.3	24.22	528.9	1041.46	332.1	653.94
Normally Open Contact	37	24	24.2	12.80	895.4	473.6	580.8	307.2
Normally open proximity switch	87	49	24.2	12.80	2105.4	1113.6	1185.8	627.2
Proximity sensor	6	3	42.3	53.20	253.8	319.2	126.9	159.6
Exhaust	4	4	598	349.00	2392	1396	2392	1396
Pressure source	2	2	96.7	90.00	185.4	180.00	185.4	180.00
Unidirectional pump	1	1	34.2	191.01	34.2	191.01	34.2	191.01
Solenoid, DC/AC	8	4	12.3	15.00	98.4	120	49.2	60
		Total			6775.7	5117.86	3982.8	3685.94

IV. CONCLUSION

The paper has presented a bill of engineering management of evaluation following a cost and minimization approach by applying the Karnaugh map optimization technique. The K-map optimization technique has proved

sufficient in this study for the reduction of the components performing similar functions during time in an industrial process, to top of production materials, production, and prof, it maximization.
The corking, stamping and, pillarization process of an industrial brewery was considered, the sensor components of the system were described and established in a K-map study for optimization using their path sequence. The optimized path sequence is used to develop a call-up table for determining the number of sensor components with similar action.

A BEME was carried out to determine the cost of the original and optimized system for two different manufacturing brands Festo and Allen Bradly in USD, and the BEME shows that the cost of the industrial setting using the optimized approach was lower.

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