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Application of Shewhart Control Chart to Analyze the Effect of Income on Body Mass Index and Blood Pressure

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ABSTRACT

This study investigates whether the level of income influences body mass index and blood pressure and we also determine whether there is a positive or negative correlation between the study variables (income, body mass index, and blood pressure). The Shewhart control chart procedure was applied to determine the effect of income on body mass index and blood pressure on subgroup categories. The Pearson correlation procedure was used to determine the relationship between the study variables. The findings showed that the percentage of high-income earners is higher with respect to normal body mass index (normal weight) than middle and low-income earners, respectively. The result also revealed that the percentage of low-income earners with normal blood pressure is higher compared to middle and high-income earners. The analysis indicates that the percentage of elevated blood pressure and hypertension is higher for middle and high-income earners than low-income earners. The result showed a weak negative correlation (r =-0.33) between income and BMI and a very strong positive correlation (r = 0.88) between income and blood pressure. This study concludes that the level of income influences body mass index and blood pressure based on working-class categories and lifestyle.

Keywords: blood pressure, body mass index, control charts, income, obesity.

1 INTRODUCTION

Statistical quality control is vital in monitoring the quality improvement of services and improving the quality of the manufacturing process due to variations [1,2]. This idea was advanced by a physicist named Walter Shewhart in 1924 [3,4]. Shewhart observed that variation is present in all processes and that variations can be classified due to common causes or special causes or simply put "chance cause and assignable cause" [5]. He coined the control chart to differentiate between the two causes of variations. It was applied to show the variation due to common and special causes of variations. When the variations are established, the system can be improved based on the types of variation observed. Shewhart classified control charts as attribute (u, c, np p), and variables such as $\bar{x}$ and R, $\bar{x}$ and std, XmR charts [6-11]. The Shewhart chart consists of three major cutoff points, namely the lower control limit (LCL), mean line or centerline (ML or CL), and upper control limit

(UCL). Each of these lines plays a vital role in analyzing variations. The LCL and UCL are computed based on 3σ limit from the mean line.

In general, the application of control charts by manufacturers requires two categories [12]: 1) Primary: detect the special cause of variation based on the data set collected using the required computational formula to obtain the center line, UCL, and LCL [13,14]. In this category, the out-of-control points and in-control points can be detected easily. 2) Secondary: mainly focus on monitoring the process based on the output of the primary category. In practice, the Shewhart control chart is useful in the primary category while the second category applies the exponentially weighted moving average and cumulative sum charts. It is worthy to note that "statistical process control" and "statistical quality control" are used interchangeably both are coined based on variations and a control chart is the core ingredient required to study both. Although, statistical quality control has evolved into different research areas.

The concept of Shewhart was to improve the quality of manufactured products and it was first used in a laboratory [15,16] and since then it has been applied to different fields of study such as healthcare, hospital, transportation, surgery, education, services, loan, and car dealers, invoicing, sales and logistics [15,17-23]. The control chart is the fulcrum of statistical process control and has been applied extensively in the healthcare and service sectors [24-27]. It is very easy in the manufacturing process to return out of control process to in control state but in other applied areas like healthcare, it requires time. It was observed that the Shewhart control chart is more efficient if the data set is normally distributed and inefficient if the data set is not normally distributed, which implies that the Shewhart control chart is not robust against influential data points [28-30].

The Pearson correlation is an established procedure to study the relationships between two variables of interest [31,32]. It has been extended to study more than two variables [33]. The Pearson correlation procedure has been applied to study the relationships between different variables of interest related to Covid-19 [33]. Researchers from different backgrounds have utilized the simplicity and strength of the Pearson correlation procedure to analyzed useful results for several decades [34-36].

Research on body mass index and blood pressure has been reported by Mohammed et al. [37] and Ozilgen [38]. However, this research differs from the above mentioned because this study combined income, body mass index (BMI), and blood pressure (BP) while research by Mohammed et al. [37] and Ozilgen [38] reported the number of observations for BMI and BP respectively. The application of the Shewhart control chart to determine the influence of income level on body mass index and blood pressure is novel and differs from the conventional application to the manufacturing process. In the context of this discussion, underweight is classified as out of control, overweight is classified as upper in control state, and obesity is out of control. Low blood pressure and high blood pressure are considered out of control, putting such conditions in the state of in-control requires time and resources. In this study, putting the out-of-control process in the state of in-control requires pharmacological and non-pharmacological procedures and is time-dependent, unlike the primary category in the manufacturing process. This paper investigates whether the level of income influences body mass index and blood pressure. We also considered the application of the Pearson correlation procedure to investigate the relationship between the study variables (income, body mass index, and blood pressure). The objectives of this paper are (1) to determine whether income level influences body mass index and blood pressure; (2) to determine whether income level correlate positively or negatively with body mass index and blood pressure. Furthermore, we adopt the concept by Paul and Barnett [39] whereby the correlation of the data set was determined before constructing the control chart.

The rest of this paper is organized as follows: Section 2 describes materials and methods which include the Shewhart control charts, Pearson correlation coefficient, and data collection, while the result and discussion follow in section 3. The final section provides the conclusion.

2. MATERIAL AND METHODS

The data set was obtained via google form which was distributed based on the concept of a simple random sampling approach to working-class people resident in Kedah state, Malaysia. Then the Shewhart control chart ($\bar{X}$ *and std*) procedure was used to determine the within and out of control points. Applying the mean and standard deviation chart, the sample size is relatively large, that is n>10 [40]. The Pearson correlation was applied to determine the existence of possible relationships between income, body mass index, and blood pressure. SAS Enterprise Guide 7.1 was used to construct the control charts.

2.1 Shewhart Control Chart

The Shewhart control chart is a pictorial display of processes based on measured characteristics. The measured characteristics help to differentiate common causes of variation from special causes of variation. Walter Shewhart advanced the process in the mid-1920s [6,13]. The Shewhart control chart consists of the mean line (centerline), lower control limit (LCL), and upper control limit (UCL) [37]. It is intuitive to note that the data points within zone A and zone C to zone A* are due to the common cause of variation [6]. However, data points outside these zones are due to special causes, such points are in a state of out of control which requires immediate attention to return the system into the within zones. The last two are defined based on three standard deviations (σ) to determine the variations from the mean line. Applying the Shewhart concept in this study, participants whose body mass index and blood pressure are classified as underweight, overweight, obese (out of control), low and high blood pressure are due to common causes of variation as well as special causes of variations.

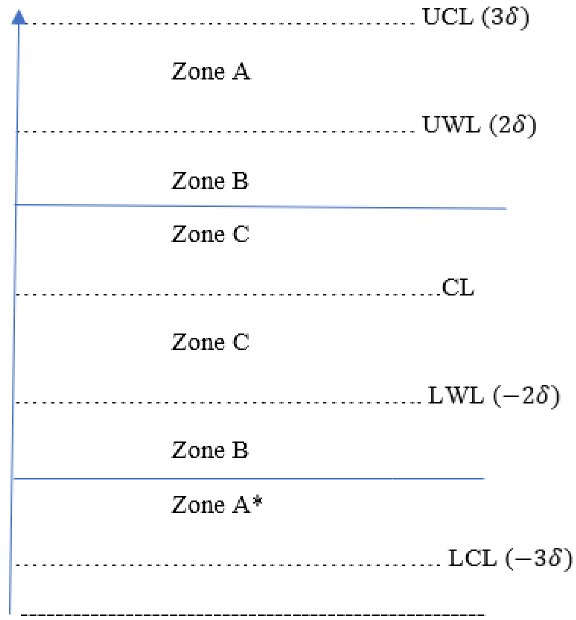

Figure 1: Control chart showing the zones.

2.2 The S Chart

Let $X = (x_k, k = 1,2, \ldots, n)$ be the data points of interest and assumed to be normally distributed, that is $X \sim N(\mu, \sigma)$ with known mean and standard deviation. The sample mean can be computed as Equation 1.

$$\bar{X}_i = \frac{\sum_{k=1}^{n} x_k}{n} \quad (1)$$

$$\bar{\bar{X}} = \frac{\sum_{i=1}^{m} \bar{X}_i}{m} = \frac{\sum_{k=1}^{m} \sum_{l=1}^{n} X_{ki}}{\sum_{k=1}^{m} n_k} \quad (2)$$

Equation 2 is the center line or the mean line. Let S denotes the sample standard deviation, then the sample standard deviation for the subgroup is defined as Equation 3.

$$S_i = \sqrt{\frac{\sum_{k=1}^{m} (x_i - \bar{x})^2}{m-1}} \quad (3)$$

Assuming that the distribution is normally distributed, then the sample standard deviation can be estimated by $c_{4*}\sigma, where\ c_{4*}$ rely on the sample size (c_{4*} is a constant) [40].

Therefore, the standard deviation of S is given as ∇ where $\nabla = \sqrt{(1 - {c_{4*}}^2)}$. Then the average of S_i for each subgroup is

$$\bar{\bar{S}} = \frac{\sum_{i=1}^{m} S_i}{m} \quad (4)$$

Therefore, Equation 4 denotes the center line while Equation 5 and Equation 6 are the upper and lower control limits, respectively.

$$\bar{\bar{S}} + 3\omega\nabla \qquad (5)$$

$$\bar{\bar{S}} - 3\omega\nabla \qquad (6)$$

Where $\omega = \frac{\bar{\bar{S}}}{c_{4*}}$ is an unbiased estimate of the population standard deviation. From Equation 5 and Equation 6, the following constants are defined

$$B_{4*} = 1 + \frac{3}{c_{4*}}\nabla \qquad (7)$$

$$B_{3*} = 1 - \frac{3}{c_{4*}}\nabla \qquad (8)$$

Similarly,

$$B_{4*} = \frac{B_{6*}}{c_{4*}}, B_{6*} = c_{4*} + 3\nabla$$

$$B_{3*} = \frac{B_{5*}}{c_{4*}}, B_{5*} = c_{4*} - 3\nabla$$

Recall Equations 7, 8, 5, and 6, these equations can be summarized as follows

$$B_{4*}\bar{\bar{S}} \qquad (9)$$

$$B_{3*}\bar{\bar{S}} \qquad (10)$$

Hence for the S control chart, the center line, upper and lower control limits are computed based on Equations 4, 9, and 10, respectively.

Based on the definition of ω we have

$$\bar{\bar{X}} + \frac{3\bar{\bar{S}}}{c_{4*}\sqrt{m}} \qquad (11)$$

$$\bar{\bar{X}} - \frac{3\bar{\bar{S}}}{c_{4*}\sqrt{m}} \qquad (12)$$

From Equation 11 and Equation 12, $A_{3*} = \frac{3}{c_{4*}\sqrt{m}}$. Hence the mean control limits are defined as follows.

$$\bar{\bar{X}} + A_{3*}\bar{\bar{S}} \qquad (13)$$

$$\bar{\bar{X}} - A_{3*}\bar{\bar{S}} \qquad (14)$$

Equations 13 and 14 are the upper and lower control limits respectively while Equation 2 is the center line for the mean control chart. The values of A_{3*}, B_{3*} and B_{4*} are obtained from the statistical tables.

2.3 Pearson Correlation Coefficient Procedure

The Pearson correlation coefficient [31] is defined as follows.

$$r = \frac{\sum_{n=1}^{k}(x_n - \bar{x})(y_n - \bar{y})}{\sqrt{\sum_{n=1}^{k}(x_n - \bar{x})^2 \sum_{n=1}^{k}(y_n - \bar{y})^2}}, \tag{15}$$

where $x_n \in X, y_n \in Y, n = 1,2,3, \dots, k$ are random variables. The sample mean vectors are stated as $\bar{x} = \frac{\sum_{n=1}^{k} x_n}{k}$ and $\bar{y} = \frac{\sum_{n=1}^{k} y_n}{k}$, respectively. Equation (15) is applied to determine the relationship between two variables. The multivariate extension of Equation (15) was discussed extensively in [33]. The numerical strength and sign direction of Equation (15) is defined as $-1 \leq r \leq +1$. The strength of the relationship is analyzed based on the numerical value and sign directions of Equation (15).

2.4 Data Collection

Data types play a vital role in choosing the type of control charts to be constructed. Data can be classified as discrete or continuous. A discrete data set is obtained by the counting process while continuous data is based on measurement. This study focused on the continuous data set, e.g., body mass index, blood pressure, and income. For this data set, mean and standard deviation charts are applied to analyze the effects of income on body mass index and blood pressure. The data set was collected via a google form. The google form was distributed to working-class people resident in Kedah state, Malaysia using different social media platforms. The responses were obtained based on a simple random concept from the respondents of the different working-class categories. This study was particular to residents of Kedah state in Malaysia, and it can be generalized to other states, the entire country, and other countries to study the influence or effects of income on body mass index and blood pressure. About 143 participants responded for the body mass index and income with an average age of 32.53 years, 69 males and 74 females while 120 people responded for the blood pressure and income study group with 70 males and 50 females with an average age of 41.35 years, respectively.

Constructing control charts requires a minimum of twenty-five data points the contrary is suitable provided is not less than ten data points. The variable chart such as mean and standard deviation, mean and range, individual and moving average (XMR) is suitable for continuous data set. In this study, the $\bar{X}$ and standard deviation charts are applied. The reason for using this chart is to determine the variations in the variables of interest. The Pearson correlation procedure was also applied to determine the relationships between the study variables.

3. RESULT AND DISCUSSION

Overall, the study showed that 65.7% of the income and body mass index participants have normal weight, 29.4% overweight, and 4.9% obese. Based on subgroup classification analysis, the high-income earners have 86.1% normal weight followed by middle-income earners with 67.3% and low-income earners with 51.7%. Also on subgroup classification, low-income earners have 44.8% overweight followed by middle-income earners 24.5% and 11.1% for high-income earners. The middle-income earners have the highest obesity (8. 2%) followed by low-income earners (3.5%) and 2.8% for high-income earners on a subgroup basis. The overall analysis for the income and blood pressure, 43.3% have normal blood pressure, 24.2% have elevated blood pressure, 30.8% have stage 1 hypertension, and 1.7% have stage 2 hypertension. On subgroup classification, 87% of the low-income earners have normal blood pressure and 13% elevated blood pressure while 10.6% of middle-income earners have normal blood pressure, 46.8% have elevated blood pressure, 40.4% stage 1 hypertension, and 2.2% stage 2 hypertension. For the high-income subgroup, 94.7% have stage 1 hypertension and 5.3% stage 2 hypertension, respectively.

Table 1: WHO Classification of body mass index

WHO classification	Underweight	Normal weight	Overweight	Obesity
BMI (kg/m^2)	<18.6	18.6 -24.9	25 -29	>30

Table 2: Level of income classification

Low income (RM)	Middle income (RM)	High income (RM)
1,000-3,000	>3,000-6,000	>6,000-above

Table 3: Summary statistics for income and BMI data

Variables	$\bar{x} \pm std$
Income (RM)	4,382$\pm$2,639
BMI (Kg/m^2)	23.96$\pm$3.358

Pearson correlation $\rho = -0.33$.

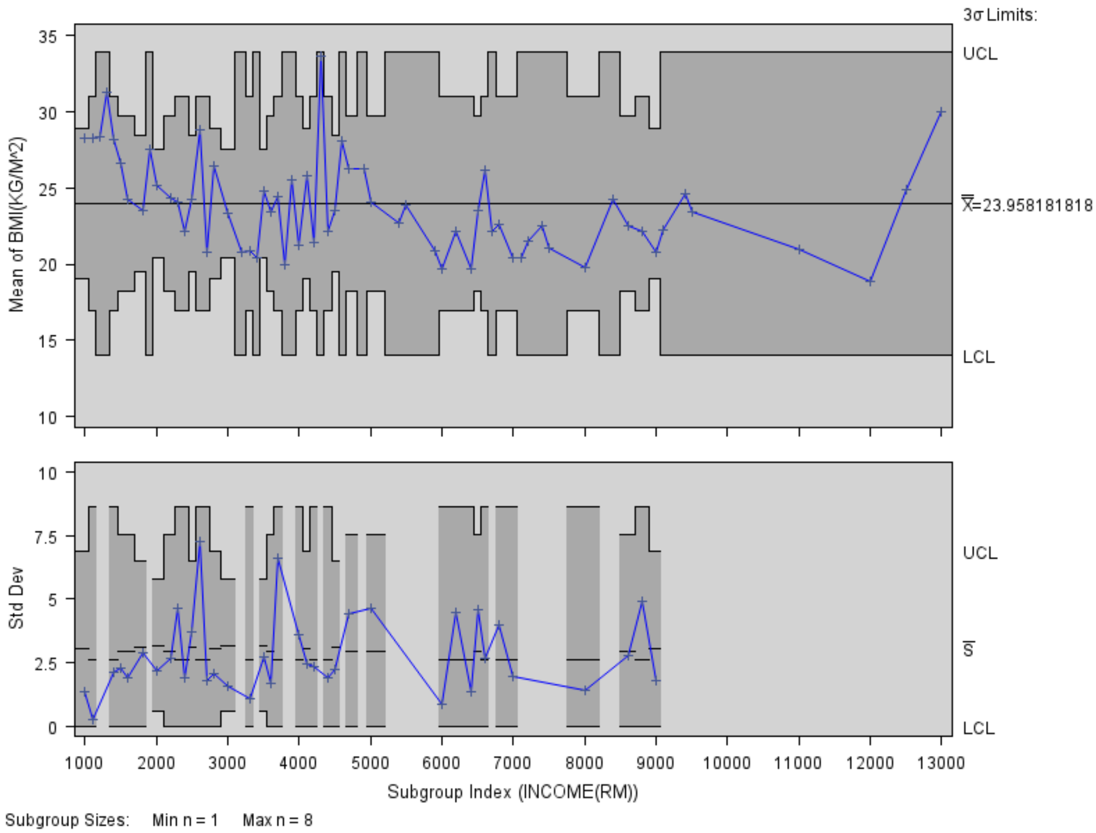

Figure 2: Mean and standard deviation control charts for income and BMI

The analysis in Figure 2 is based on the benchmark in Table 1 and Table 2, respectively. Both tables consist of the information required to construct the $\bar{X}$ and the standard deviation charts. Table 3 shows the summary statistics, the variation in income is large while variation in the BMI is relatively a normal weight based on WHO classification in Table 1. However, the mean value of the BMI mimics the normal body weight as shown in Table 1. From Figure 2, for the low-income subgroup, 51.7% have normal body weight (in state of in control), 44.8% are overweight (zone A, state of in control) and 3.5% are obese (out of control). For the middle-income earners, 67.3% normal body weight (state of in control), 24.5% are overweight (upper zone of the state of in control) and 8. 2% are obese (out of control) while in the high-income subgroup, 86.1% normal body weight (state of in control), 11.1% overweight (zone A, state of in control) and 2.8% obese (out of control). Overall, 65.7% of the entire participants have normal body weight (are in the state of in control) while 29.4% are overweight (zone A, state of in control) and 4.9% are obese (out of control). From Figure 2, the value of the center line is within the WHO classification of the state of in control for body weight. The result is very close to WHO classification and more realistic than the overall average reported by Ozilgen [38] based on this data. ***Remark 1:*** Relying on this finding, a high percentage of low-income earners have a higher percentage of above normal body mass index whereas a high percentage of people with higher income levels have normal body mass index.

Table 4: Classification of blood pressure [41]

NBP (mmHg)	Elevated BP (EBP)	Stage 1 (HBP)	Stage 2 (HBP)
115/75-120/80	120/80-139/89	140/90-159/99	160/100>

NBP: Normal blood pressure; EBP: Elevated blood pressure; HBP: high blood pressure

Table 5: Summary statistics for income and BP (mmHg)

Variables	$\bar{x} \pm std$
Income (RM)	$4{,}068 \pm 2{,}423$
BP (mmHg)	133.65 ± 11.07

Pearson correlation $\rho = 0.88$

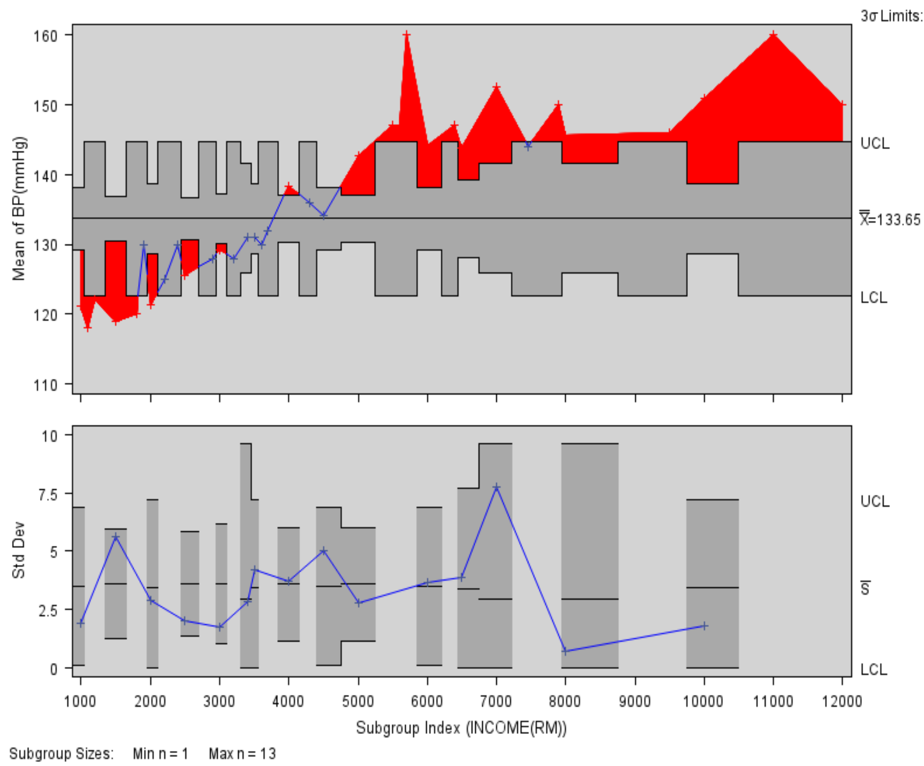

Figure 3: The mean and standard deviation for income and BP (mmHg)

Table 4 contains the benchmark of systolic blood pressure (BP) used in analyzing whether participants are within or outside control zones. Table 5 contains the summary statistic for the data set. From this table, the average income and the BP are presented. The standard deviations for income and BP are relatively large, implying the extent of data point variation. However, the average BP in the control chart shows elevated blood pressure. This is based on a comparison with the information contained in Table 4. From Figure 3, for the low-income subgroup, 87% have normal blood pressure (state of in control) and 13% elevated blood pressure (zone A or B, state of in control).

In this subgroup, no stage 1 (out of control) or stage 2 (out of control) case was observed. For the middle-income subgroup, 10.6% have normal blood pressure (NBP) (state of in control), 46.8% have elevated blood pressure (EBP) (zone A or B, state of in control), 40.4% have stage 1 blood pressure (S1-BP) (out of control) and 2.2% have stage 2 blood pressure (S2-BP) (out of control zone). For the high-income subgroup, 94.7% have stage 1 (S1-BP) (out of control) and 5.3% have stage 2 (S2-BP) (out of control), with no case of normal or elevated blood pressure. Although the center line value based on the data set is within the elevated blood pressure but more realistic than the center line value reported by Mohammed et al. [37]. ***Remark 2:*** The lower the income, the normal the blood pressure whereas as the income increases the blood pressure also increases based on this data set.

The result showed a weak negative correlation (r =-0.33) between income and BMI and a very strong positive correlation (r = 0.88) between income and blood pressure. The study revealed that income and body mass index (kg/m^2) is negatively correlated while income and blood pressure ($mmHg$) is positively correlated.

3.1 Discussion

From this study, the low-income subgroup has the highest percentage of overweight (44.8%) closely followed by the middle-income subgroup with 24.5%, and the high-income subgroup which has the lowest percentage of overweight (11.1%) and obesity (2.8%). The high-income subgroup has the highest percentage of normal weight (86.1%) followed by the middle-income subgroup (67.3%) and the low-income subgroup have the lowest normal body weight (51.7%). In this study, we did not observe any underweight participants however, the overweight and obese are out-of-control data points that can be put into a state of in-control, though it requires time and resources. The findings based on the center line value are consistent with WHO classification and comparable with the findings by Ozilgen [38]. From this study, we observed that the high-income subgroup has a considerable normal bodyweight that is within the normal body weight classification. On the other hand, some participants in the low-income subgroup are overweight and obese. This may be due to educational background, exposure, and eating habits or lifestyle while the high-income subgroup may control their eating habit and often exercise. For the low-income subgroup, 87% have normal blood pressure and 13% elevated blood pressure while in the middle-income subgroup, 10.6% have normal blood pressure, 46.8% are categorized as having elevated blood pressure, 40.4% stage 1 hypertension, and 2.2% stage 2 hypertension, respectively. For the high-income subgroup, 94.7% have stage 1 hypertension and 5.3% have stage 2 hypertension. From this study, 43.3% of the entire subgroups have normal blood pressure, 24.2% have elevated blood pressure, 30.8% have stage 1 hypertension, and 1.7% have stage 2 hypertension, respectively. The findings in this study based on the data set are comparable to the findings reported by Mohammed et al. [37]. For the control chart application, the stage 1 BP(S1-BP) and stage 2 BP(S2-BP) are out-of-control data points and to put them in a state of in-control requires time and resources such as pharmacological and non-pharmacological procedures. ***Remarks 1-2*** are the classical results of this study. The study also showed that some high-income earners suffer high blood pressure than some low-income earners. The study showed that income and body mass index correlates negatively ($r = -0.33$) while income and blood pressure correlate positively ($r = 0.88$). The finding demonstrated that income level influences BMI and BP, respectively.

4. CONCLUSION

This study based on control chart analysis revealed the effects of income level on body mass index and blood pressure. This study on subgroup analysis showed that some low-income earners are overweight and obese more than some middle- and high-income earners. The analysis also revealed that some high-income earners have a normal body weight than some middle and low-income earners in that order. For the income level and blood pressure study on subgroup analysis, the findings revealed that some low-income earners have a normal blood pressure than some middle-income and high-income earners in that order. The study demonstrated that some middle-income earners have elevated blood pressure than some low-income earners. Meanwhile, the study indicated that some middle-income and high-income earners have the highest cases of stage 1 hypertension and stage 2 hypertension based on the data set used for this study. The out-of-control data points such as obese, prehypertension and hypertension can be put into the state of in control, though require time and resource. To put these individuals in the state of in-control requires pharmacological and non-pharmacological procedures. The findings revealed that income and BMI are negatively correlated, while income and blood pressure are positively correlated. The study concludes that income of different levels has a different effect on people.

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