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An Investigation into the Use of Laney U Chart as a Visual Schedule Tracker to Graphically Monitor the Schedule Performance Index

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Abstract: The intent of this article is to explore a mathematically sound method to graphically monitor schedule performance index (SPI) such that it enables the project manager to take objective data based decisions regarding the progress of the project schedule. The article aims to leverage the theory and application of control charts, specifically the U chart and Laney U chart and test its applicability to earned value management by trending schedule performance index on a time series chart. Off the shelf software, Minitab™ was used to generate the control charts based on earned value and planned value. While this paper proves that the Laney U chart, with correct interpretation, acts as an effective trigger-based tool for schedule risk management, it also generates further avenues for research into similar use of control charts for cost performance and other quality indices.

Keywords: Schedule performance index, SPI, control chart, Laney U chart, U chart, schedule performance management, and schedule risk management.

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1. Introduction

Earned value management is a proven technique, which has consistently been used for more than a decade across a variety of industries and functions to quantitatively track the schedule and costs of a project (Fleming and Koppelman, 2016). The popularity of this technique is rooted in its simple costs based logic, which is easy to understand and implement. This simplicity also renders it available to common misinterpretations. The schedule performance index (SPI) of '1' may mean that the project is on time or the project is completed, and, as the project nears its critical ending phases, SPI is expected to hover near '1' since schedule variance converges to zero. Thus while still having value by showing a 'snapshot in time' these indicators lose their predictive ability (Vandevoorde and Vanhoucke, 2006) about halfway through the project as historical data starts having a higher weight. Lipke (2003) has elaborated on this in detail. Many meritorious articles have been written describing techniques to overcome these apparent fallacies of SPI, such as Anbari (2003), Jacob (2003) and Lipke (2003), the latter of which introduces the concept of earned schedule by focusing on the time dimension for schedule tracking (all of these methods have been comparatively analyzed in Vandevoorde and Vanhoucke (2006)). All the previously mentioned articles have large academic merit, however, they introduce a higher complexity of mathematical calculations and do not provide a holistic graphical measure that lends itself to a simple, fast and practical analysis. By leveraging methods of statistical process control, this paper aims to test the applicability of a novel method of tracking SPI using statistical control charts throughout the duration of the project such that it enables easy decision making by virtue of an engaging graphical format without gaining any mathematical complexity.

2. Method

Statistical process control (SPC) is a discipline which uses control charts to optimize the performance of a system by assigning control limits and tracking the system performance via sampling and placing the sampled arithmetic on a charted scale either between the control limit (stable observation) or outside the control limit (unstable observation) (Oakland, 2007). Lipke and Vaughn (2000) go into details of the applicability of SPC to earned value (EV) analysis.

In all control charts, the control limit is determined by calculating three sigma deviation from the historical mean which defines 99.7% of statistical variation. The statistical calculations and their accuracy highly depend on underlying distribution and its stability. An important point here is the use of the word 'statistical', which implies sampling, to predict population behavior.

This sampling provides the sample mean of a subgroup upon which further calculations are based on. For e.g., if a three-sigma limit is 5 units and the observation is 2 units, the conclusion is that there is a 99.7% chance that the population is within control and does not exceed the set trigger variation of 5 units but there is also a 0.3% chance that this statistic may be wrong.

When one has a complete set of unsampled data i.e. data which represents the whole population, the error parameter is rendered meaningless as there is no sampling but the rest of the virtues of the control charts still apply because the validity of the control limit calculation still holds.

Hansen (2007) discusses the charting of population control charts for population data and provides rationale for above-mentioned statement. In this vein, there have been numerous papers, which have aimed to leverage the power of control charts to track SPI. Most notable of them was Lipke (2002) which explains the usage and challenges of X-mr control charts to track SPI. These charts are individual and moving range control charts for a subgroup of one and are useful when only one observation is made per time period.

The theoretical principles underlying X-mr chart are three: 1) samples are from normal distribution 2) samples are independent and identically distributed 3) samples are randomly selected (Leu et al., 2006). The schedule variance data, specifically the earned value and planned value (PV) usually does not fit within these rules and requires statistical corrections before continuous variable control charts can be used on them (Lipke, 2002).

Another option, which is explored ahead, is to re-assess the nature of the data and use the theory of attribute control charts by assuming one dollar as an attribute unit. Surprisingly, the mathematical calculations of attribute control charts, especially the U chart, lend themselves to natural adaption to tracking of SPI while maintaining mathematical simplicity.

For the application of the theory of U chart, the planned value costs act as the population size whereas every dollar is assumed to be an attribute unit. The earned value cost, which is the value of work completed to date, is the variable, which is normalized by planned value and charted to show a trend of SPI as seen in Eq. (1).

$$\text{SPI} = \frac{Earned\ Value}{Planned\ Value}$$

$$= \frac{Monthly\ Earned\ Value\ is\ the\ U\ cha\quad variable}{Monthly\ Planned\ Value\ is\ the\ U\ chart\ subgroupsize}$$

$$= \frac{x_i}{n_i} = u_i = \text{Plotted Statistic} \tag{1}$$

The accuracy of U chart to trend SPI is increased because of two things, 1) central limit theorem that states that normalized sums of independent variables tend to be normally distributed and 2) every trended SPI value is EV normalized by PV.

U chart calculates the control limit per the following formula (Moon, 2018) shown in Eq. (2) and Eq. (3).

$$\text{LCL} = \bar{u} - 3\sqrt{\frac{\bar{u}}{n}} \tag{2}$$

$$\text{UCL} = \bar{u} + 3\sqrt{\frac{\bar{u}}{n}} \tag{3}$$

Where $\bar{u}$ is the average SPI, n is the subgroup size, UCL is the upper control limit and LCL represents the lower control limit. The U chart relies on Poisson distribution to correct error due to sampling but in this case, formulas and mathematical logic adapt quite readily due to treatment of the whole population to the control chart arithmetic than a sample thereby eliminating sampling error.

The plotted statistic is shown in Eq. (4).

$$U_i = \frac{x_i}{n_i} = \frac{EV}{PV} = \text{SPI} \tag{4}$$

Thus, treating EV as the variable over PV as the population size for a particular month shall automatically create an SPI trend line. It is important to note that we are extending the logic of the U chart here and converting it from a chart of non-conformities to a chart of conformities where ‘conformity’ is the adherence of Earned value to the planned value. This ‘conformity’ is charted through the schedule performance index.

While the mathematical logic is easily extended, the hazard lies in the conversion of a chart designed to trend sample data to the population data. A hurdle in this regard is the inherent assumption of Poisson data that the mean of the distribution is constant over time. We know that for EV, this is untrue. Thus, if we aim to draw a U control chart, then by the overdispersion nature of the data, our control limits will we very close together and result in multiple out of control points as shown in Fig. 1.

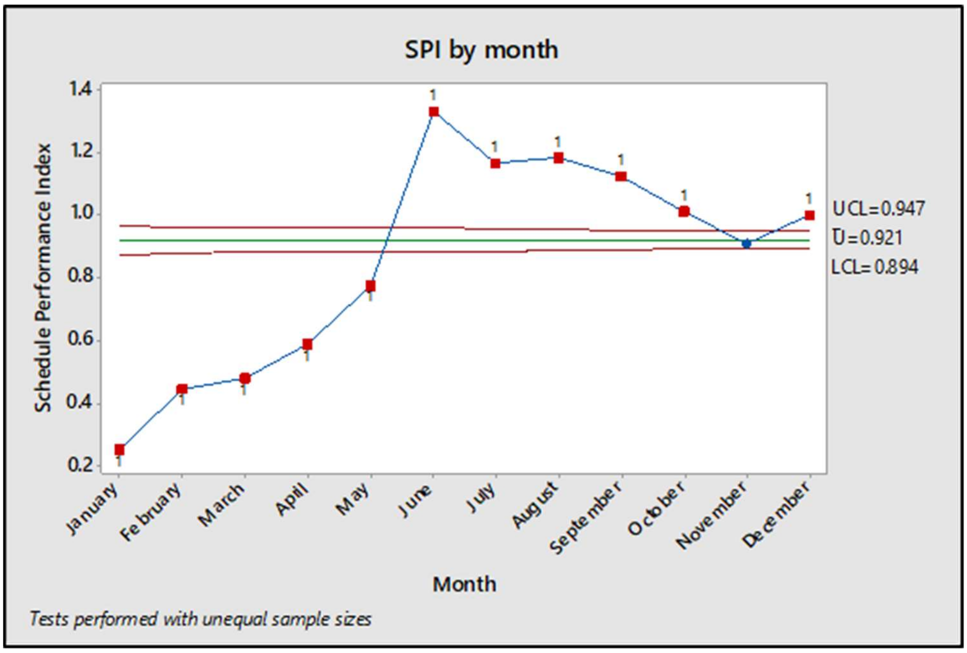

Fig.1. Multiple out of control points due to overdispersion

Table 1. Raw Data for Fig. 1

Month	EV($)	PV($)
January	1000	4000
February	2000	4500
March	2390	4990
April	3000	5100
May	4000	5150
June	8000	6000
July	8180	7000
August	8890	7500
September	9000	8000
October	9100	9000
November	10000	11000
December	12000	12000

Hence, while we were able to justify leveraging major aspects of a U Chart to calculate and trend SPI, violation of one assumption of the underlying distribution resulted in the calculation of unusable limits.

Jones and Govindraju (2001) have identified overdispersion as a problem where data points have variation in excess of an assumed probability distribution. The classical control limit formulas depend entirely on sampling variation, so when the sample sizes are very large, the limits are concentrated toward the centerline of the chart (Laney, 2002). This problem was stated by Laney (2002) to occur when sample sizes are large and can be obviously expected to occur when the whole population is considered. One solution here is to chart the previously mentioned X-mr charts as done by Lipke (2002) but this chart will result in a flat control limit throughout the period of analysis thus it does not account for varying subgroup sizes. Therefore one has to process the data first by calculating SPI, correct for distributional anomalies and then apply the theory of control chart to reproduce Lipke's (2002) results.

3. Results

Laney Charts (Laney, 2002), take into consideration both, intra and inter subgroup variations and provide subgroup specific control limits which are adjusted per the dispersion which is quantified using sigma z values (Laney, 2002). For the same data set used in Fig. 1, the following Laney U chart of SPI provides practicable and meaningful control limits. The variable for this chart is earned value while the subgroup size is the planned value for the particular month.

While the genesis of theoretical calculation of the control limits can be found in Laney (2002), simply put, this chart uses z transformation to assign a value to the z variation which is assumed to be '1' in the classical U chart. The control limits are recalculated as seen in Eq. (5) and Eq. (6).

$$\text{UCL} = \bar{u} + 3\sigma_{ui}\sigma_z \quad (5)$$

$$\text{UCL} = \bar{u} - 3\sigma_{ui}\sigma_z \quad (6)$$

Where σ_{ui} is $\sqrt{\frac{\bar{u}}{n}}$ and σ_z is the correction for dispersion (Laney, 2007). The variation is calculated as seen in Eq. (7)

$$\acute{\sigma}_z = \frac{\bar{R}}{1.128} \quad (7)$$

The mean ū is the mean of all observations of SPI until the last data point. In SPC it is common to automatically calculate this but where the expected value is known, one can manually enter a value and base control limits off this value. For example, since we know that mean represents

SPI, it is acceptable for us to assign the mean as one if a baseline is needed for absolute comparison.

These formulas are presented in detail to amply show that using monthly population values as the sample for a specified timeframe has no effect on mathematical logic. The most apparent effect of using population data over sample data was the overdispersion which was able to be explained by probability distribution assumption and which is taken care of by Laney U chart with z corrections.

Thus, the Laney U chart is a time series chart of SPI with assigned variable control limits which adjust per the stage of the project. Fig. 2 shows the graphical trend line of SPI as the project moves towards completion. As can be seen, the control limits converge towards the end, and rightly so since a higher amount of performance is expected to maintain SPI of 1 if the schedule is straggling. This particular figure shows two and three sigma standard deviation from the mean, usage of which is dependent on the tightness of control the project manager wants to exert over the SPI.

In Fig. 3, the mean has been automatically calculated and shows the mean at the end of the 12th month. To proactively track SPI, the project manager may present this chart each month to drive decision making and compare trends. For example, for the same data, the chart for the 9th, 10th and 11th month would look as Fig. 4 and Fig. 5.

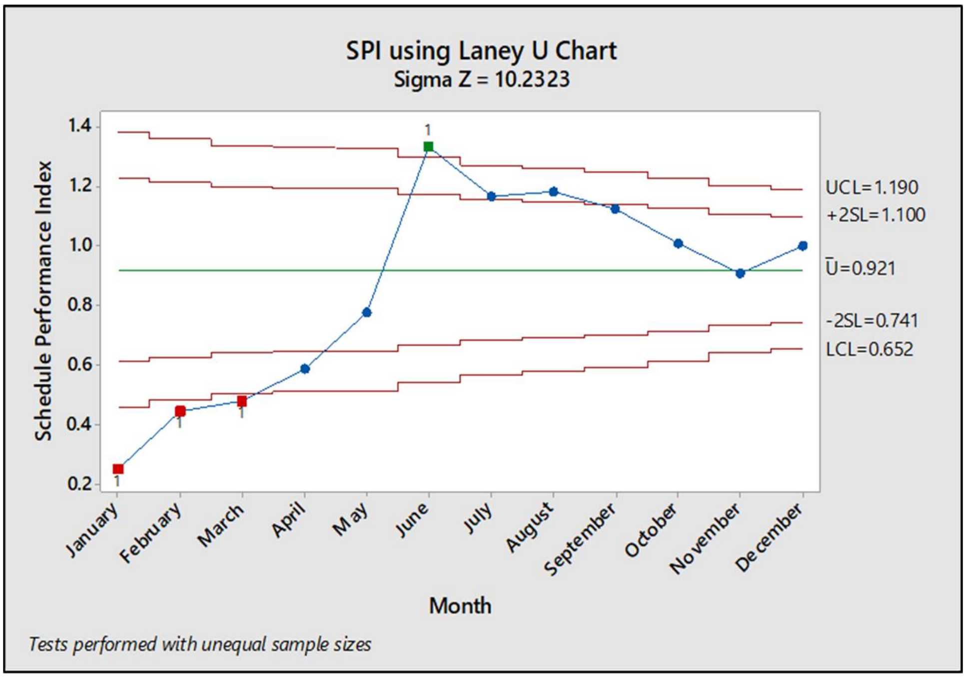

Fig. 2. Laney U chart with recalculated limits and 2,3 sigma limits

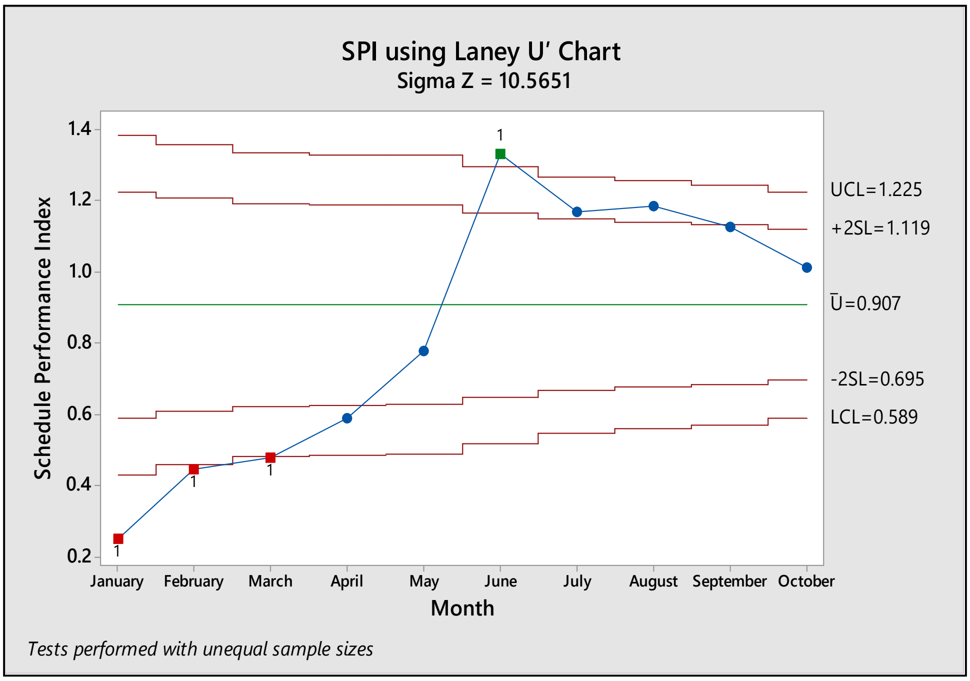

Fig. 3. SPI chart for September

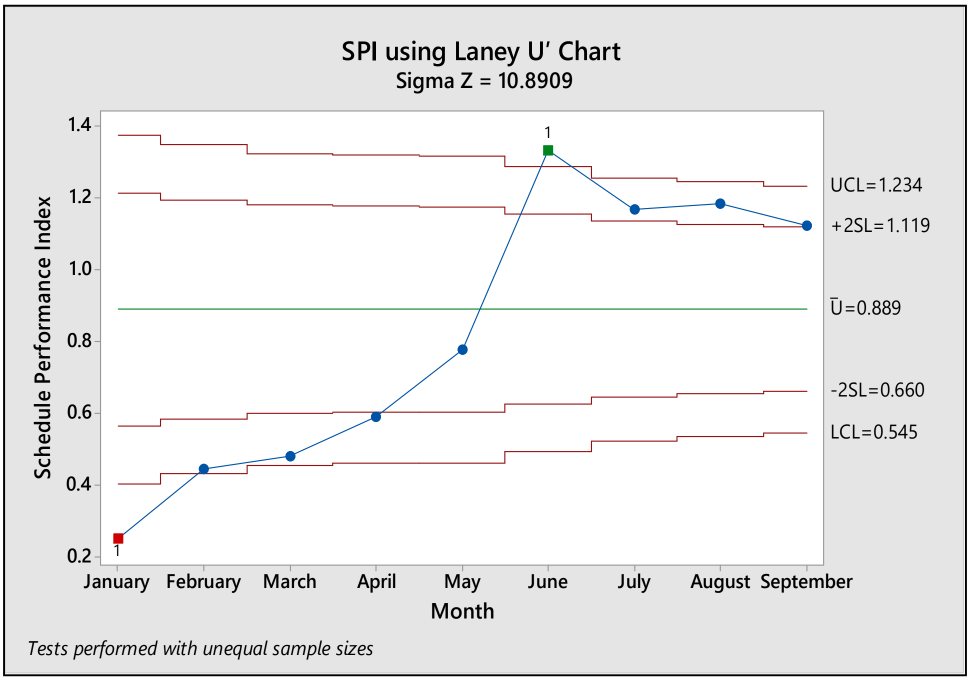

Fig. 4. SPI chart for October

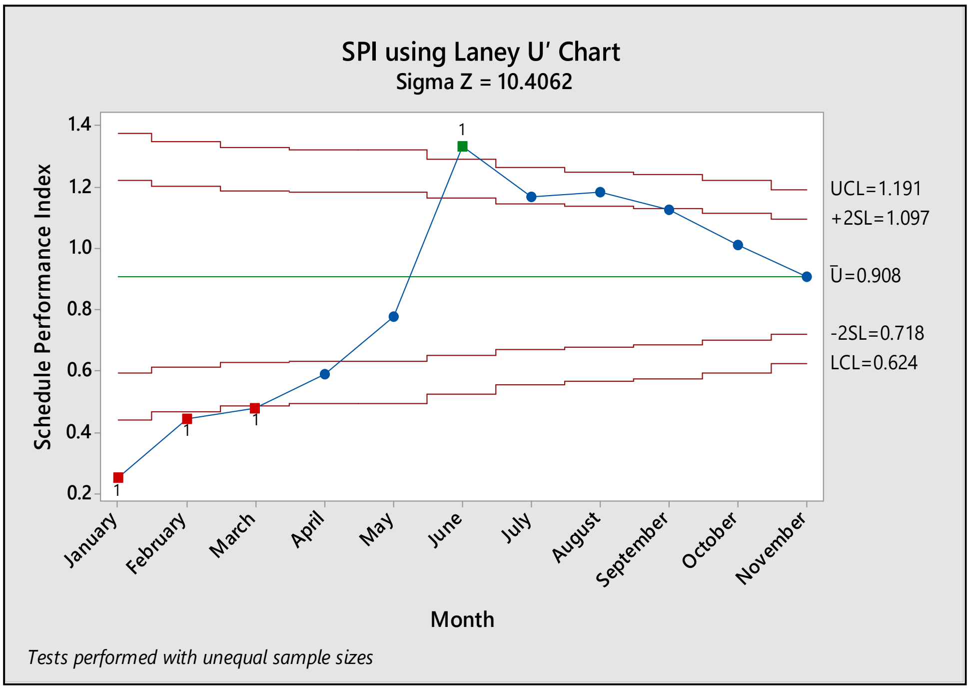

Fig. 5. SPI chart for November

As is logical and can be seen, the mean SPI changes every month based on the calculated SPI of the particular month. This may or may not be of value depending on the project metrics in the project plan. It still shows the comparison based on our predefined time period (here, monthly) but has an aspect of relativity.

4. Discussion

In the above section, the use of Laney U chart shows a graphical trend of schedule performance but does not show a difference from a set baseline.

This drawback can be overcome by assigning the mean (EV/PV) manually and tracking the changes of the monthly SPI from the mean which is the perfect SPI of 1. This shows an absolute comparison as can be seen below in Fig. 6.

Using an off the shelf software like Minitab™ a project manager can simply input the planned value and earned value and generate a graphical time based visualization of the SPI. The project manager can compare the monthly performance with historical performance and with perfect performance (of SPI=1) and thereby draw multiple conclusions as can be seen below in Fig. 7

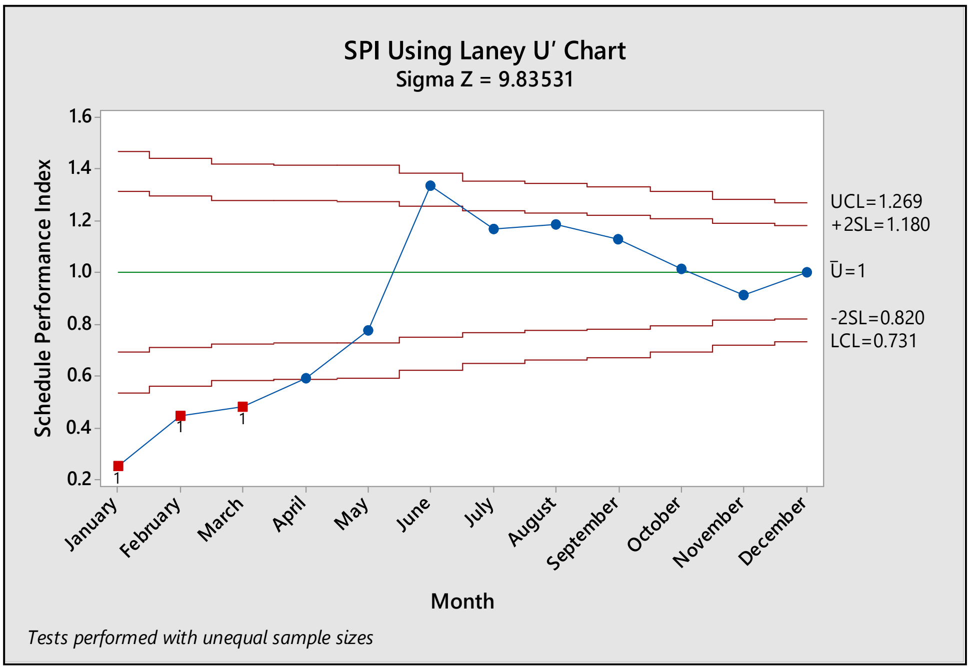

Fig. 6. SPI chart with an assigned SPI (mean) of 1

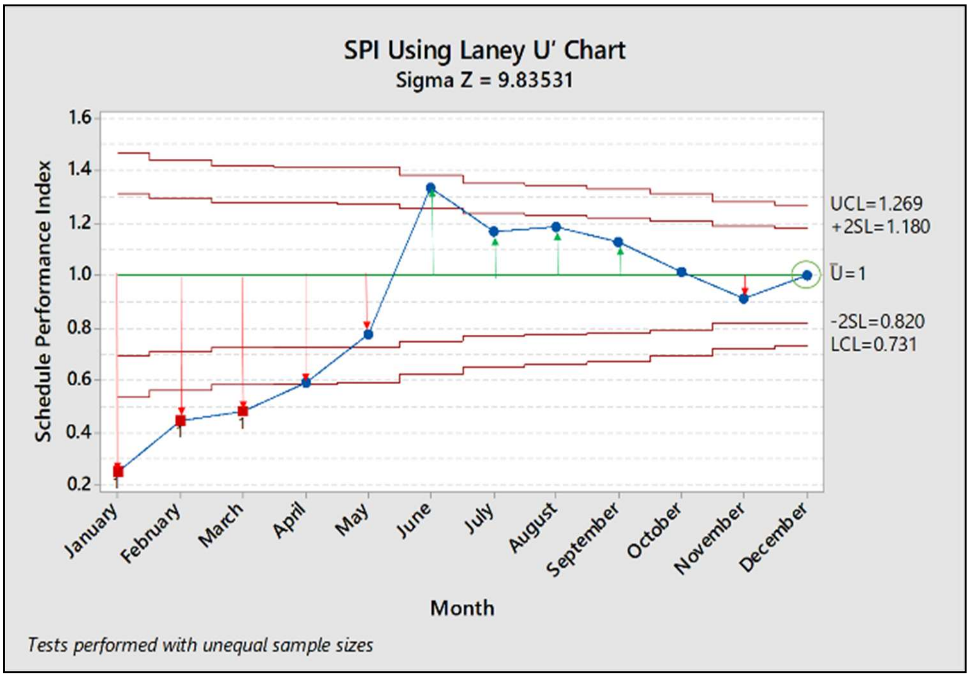

Fig. 7. SPI chart showing velocity and directionality of SPI

New research on earned value management has shown that it can provide great insight into the project progress and act as a sound decision making tool. Prayogi (2019) has attempted to track earned value and schedule variance as triggers for corrective actions for a lagging project and recommended crashing as an action to meet project schedule. SPI tracking using control charts can enable early detection of a schedule lag and also track baseline changes after actions such as crashing or fast tracking are implemented. In the same vein, Khesal (2019) has proposed a trackable quality index based on earned value which incorporates cost, quality risk and schedule. The SPI control chart shown in this article can be easily adapted to the quality index, and act as an added graphical tool which can harmonize multiple parameters in an easily presentable format.

5. Conclusion

Using the Laney U chart to track SPI has many notable benefits including:

- Improvement of planning processes
- Benchmark indication for process improvement

- Rolling performance prediction
- Monitoring project schedule risk
- Assigning trigger criterion for action.

This can be classified as a quantitative risk control tool. The time period can be modulated based on the project needs and does not have to be monthly as shown in the charts in this paper, it can be quarterly, weekly or even daily if high quality and timely data are available. Graphical representation of SPI also shows the 'velocity' of SPI and gives a directional aspect to a dimensionless constant. Not only the project manager can use this directionality combined with performance limits as an early warning signal but s/he can also show the management a mathematically valid and objective method of tracking the project and its deviation from predefined normal. Usage of the Laney U charts to track SPI helps in proactive performance management by continually checking trends and re-aligning expectations. Out of limit points should initiate a corrective action sequence and re-assessment of the timeliness goals while cues for course correction can be gleaned by the movement of individual points towards or away from the goal of SPI=1.

Future studies may be aimed at studying the applicability of various other newer control charts such as g-charts, t-charts and CUSUM charts to schedule and cost performance index. Applicability of control charts to holistic project indices like those postulated by Khesal (2019) may also provide useful insights.

References

Anbari, F. T. (2003). Earned value project management method and extensions. *Project management journal*, 34(4), 12-23.

Fleming, Q. W., & Koppelman, J. M. (2016). Earned value project management. Newtown Square, Pennsylvania: Project Management Institute.

Hansen, J. P. (2007). Population control charts for population data. *Journal for Healthcare Quality*, 29(1), 29-36.

Jacob, D., (2003). Forecasting Project Schedule Completion with Earned Value Metrics, *The Measurable News*, 1, 7-9.

Jones, G., & Govindaraju, K. (2001). A Graphical Method for Checking Attribute Control Chart Assumptions. *Quality Engineering*, 13(1), 19-26.

Khesal, T., Saghaei, A., Khalilzadeh, M., Rahiminezhad Galankashi, M., & Soltani, R. (2019). Integrated cost, quality, risk and schedule control through earned value management (EVM). *Journal of Engineering, Design and Technology*, 17(1), 183-203.

Laney, D. (2007). P-Charts and U-Charts Work (But Only Sometimes). *Quality Digest*, 14(4). Retrieved from https://www.qualitydigest.com/may07/departments/what_works.shtml on October 10, 2019.

Laney, D. B. (2002). Improved control charts for attributes. *Quality Engineering*, 14(4), 531-537.

Leu, S. S., Lin, Y. C., Chen, T. A., & Ho, Y. Y. (2006). Improving traditional earned value management by incorporating statistical process charts. *Proceedings of ISARC*, 275-280.

Lipke, W. (2002). Statistical Process Control of Project Performance. *The Measurable News*, 25-28.

Lipke, W., & Vaughn, J. (2000). Statistical process control meets earned value. CrossTalk: *The Journal of Defense Software Engineering*, 13.

Lipke, W., 2003, Schedule is different, *The Measurable News*, March 2003, 31-34

Moon, J. (2018). Theory and Application of J Charts for Holistic Risk Based Statistical Adverse Event Trending. *International Journal of Health and Economic Development*, 4(1), 9-31.

Oakland, J. S. (2007). Statistical process control. Routledge. Linacre House, Jordan Hill: Butterworth-Heinemann

Prayogi, R., Pratami, D., Puspita, I. A., & Bermano, A. R. (2019). Measuring Schedule Performance of Fiber to The Home Project Using Earned Value Management. In *2018 International Conference on Industrial Enterprise and System Engineering* (IcoIESE 2018). Atlantis Press.

Vandevoorde, S., & Vanhoucke, M. (2006). A comparison of different project duration forecasting methods using earned value metrics. *International journal of project management*, 24(4), 289-302.

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