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# PROJECT-BASED INCIDENT RATE BASED ON WEIGHTED AVERAGE METHOD

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**ABSTRACT**

*The incident rate has been widely used to indicate safety performance. The incident rate of a company can be compared with the national or international incident rate within similar industry or among different types of industries. The comparison is particularly very useful as a safety benchmark to gauge performance with other companies in the same business area. However, many existing methods produce the annual incident rate, which has been formulated on an annual basis. This will lead to incompatibility of the method used in calculating the incident rate for a project that runs for a specific period. This is because the annual incident rate does not consider the duration of the project; it becomes less meaningful in indicating the safety performance of project-based activities such as those in construction industries. The proposed method which is Project-Based Incident Rate (PIR) is found to be able to reflect the actual situation of project-based companies better than the existing annual incident rate method, and it is also can be expressed both on a monthly and yearly basis.*

**Keywords***: Construction Industry, Incident Rate, Project-Based, Safety Measure, Weighted Average.*

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## 1. Introduction

The incident rate is an indicator for various important reasons. Generally, the incident rate is a measurement of how many incidents have occurred. Based on the incidents occurring in an industry, the relationship between industrial incidents and workplace safety performance is expored. Therefore, safety measurement in a workplace is one of the most important things that contribute to the overall safety performance of an industry, a company or even a project. It can also be used to improve safety and health awareness since the performance indicates the strengths or weaknesses of the business entity.

Economic activities can be separated into several sectors, agriculture, service industries, manufacturing, construction, transportation and others (Jilcha & Kitaw, 2017). Due to the increase in the number of industries, public health issues or incidents are likely to increase as well. The construction industry is one of the main industries contributing to the economy of a country and it can become extremely progressive and profitable (Ayob, *et al.*, 2018). The workers in construction industries are likely to face many hazards that cause them temporary or permanent disabilities or even fatalities (Hosseinian, 2012). Hence, the construction sector may contribute to the highest incident rates or fatality rates as compared to other sectors.

Construction is said to be a project-based industry that has varying project durations or periods (Vrijhoef & Koskela, 2005). Hence, this factor may affect the incident rate value. In addition, the number of incidents and the average number of workers contribute to the incident rate values. The annual incident rate methods may be unsuitable for use in evaluating the incident rate for certain companies, such as a project-based company. This is because it may not reflect the actual situation if the same indicators are used. Since the annual incident rate is computed separately for each year, it can cause fluctuations which can lead to misleading evaluations and descriptions of the actual situation in the company. Therefore, this study proposes an enhanced incident rate formulation, which is a project-based incident rate based on the weighted average method.

## 2. Existing Incident Rate Formula

Nowadays, the incident rate is widely used in various industries around the world, where it is usually used as the key safety performance indicator. Although, in general, the formulation and calculation of the incident rate differ between countries, it can be observed that the formulation has two components: the total man-hours and the employment size. This section describes these two categories of the incident rate.

Every country has an agency that is usually responsible for protecting the safety and health of workers from the risks of work activity. In general, each agency has its own proposed incident rate formulation. For example, the United States Occupational Safety and Health Agency (OSHA) 2016 is a body that is responsible for monitoring and enforcing federal workplace safety regulations' compliance. It is also an example of an agency that proposes an incident rate based on the total number of man-hours, which measures how often workplace injuries occur annually at a specific company. Since the OSHA incident rate is the most well-known formula, many companies have been using it to compare their safety performance with the state average incident rate for their industry (Ogle, 2017). The incident rate proposed by OSHA is based on the number of hours worked by all employees and is defined as follows:

$$IR = \frac{Total\ number\ of\ injuries}{Number\ of\ hours\ worked\ by\ all\ employees} \times 200,000 \tag{1}$$

Note that the value of 200,000 in the formulation refers to the standard total labour hours in a year such that it represents a log of 100 employees over 50 weeks, based on a 40-hour working week. This means that the OSHA incident rate calculates the number of employees that have been injured for every 100 employees in that particular year.

Many other countries have adopted an incident rate formulation based on employment size. This includes Malaysia (Department of Occupational Safety and Health Malaysia, 2021), Australia (National Occupational Health and Safety Commission Australia, 1990), Hong Kong (Hong Kong Labour Department, 2021), India (Bureau of Indian Standards, 2013), Singapore (Singapore Ministry of Manpower, 2017) and the United Kingdom (U.K Health and Safety Executive, 2018). Although the formulations differ slightly between the countries mentioned

above, the obvious difference is the multiplication of the incident rate by the number of employees to indicate the incident rate per number of employees. For example, in Malaysia, it is expressed per thousand persons employed. Meanwhile, in Singapore, it is expressed per hundred thousand persons employed and, in Australia, it is expressed per hundred persons employed. Therefore, the general formulation of the incident rate based on employment size can be written as follows:

$$IR = \frac{I}{W} \times employee\ \ population \tag{2}$$

where $I$ is the number of reportable incidents and $W$ is the average number of workers. In essence, the incident rate methods mentioned above, including the OSHA incident rate, have been formulated to calculate the incident rate annually. This means that it might be suitable only for companies that operate continuously without having a specific project duration. Hence, the annual incident rate methods may be unsuited to the measurement of the incident rate for project-based activities, such as in the construction industry. It is important to note that, in the current incident rate formulation, the number of incidents and the number of workers or hours worked become the only main aspects contributing to the incident rate value. This can be misleading or cause errors in the incident rate calculation since it does not take into account the weight of the incident rate, which is the duration of the project. Moreover, the annual incident rate methods can cause fluctuations in the result since the incident rate value is calculated solely and separately for each year without averaging it with the previous years, which may lead to an unreasonable incident rate value.

## 3. Proposed Project-Based Incident Rate based on Weighted Average Method

The weighted average is a method for calculating an average whereby some values have greater weight than others (Grela, 2013). In other words, the weighted average takes into account the portions that may have uneven representation, and it accounts for them by ensuring that the final product reflects a more stable and equal interpretation of the data. The standard formulation for the weighted average (Grela, 2013) is defined as follows:

$$Weighted\ \ Average = \frac{\sum_{i=1}^{n} P_i q_i}{\sum_{i=1}^{n} P_i} \tag{3}$$

where $p_i$ is the weight, $q_i$ is the feature and $i = 1, 2, 3, ....., n$ is the number of features. The benefit of using a weighted average is that it is not only easy to compute and understand, but it also offers the probability of differentiating weights of the dimensions and the result obtained shows the same measure as the component variables. Although the result obtained using the weighted average may be slightly different from the result obtained using a simple average, the weighted average is able to smooth out fluctuations in the result (Ganti, 2021). This means that the weighted average reflects a more long-term and consistent valuation. Therefore, this study proposes a project-based incident rate (PIR) based on the weighted average method. Basically, PIR is an enhanced incident rate method formulated after comparing the previous incident rate methods and considering various factors and problems that can influence that value of incident rate, which include the duration of a project. Since the PIR is based on the weighted average method, this means it can take into account not only the number of incidents and the number of

workers, but also the project duration, such that the method can be used to indicate the incident rate at any specific time during the progress of the project. Therefore, the PIR can be calculated either monthly or annually. The formulation of the project-based incident rate can be defined as follows:

$$PIR = \frac{\sum_{i=1}^{n}\left(\frac{I_{y_i}}{W_{y_i}} \times d_{y_i}\right)}{\sum_{i=1}^{n} d_{y_i}} \times 1,000 \tag{4}$$

where $y_i$ refers to the year $i$ , $I_{yi}$ is the total number of incidents for that year, $W_{yi}$ is the average number of workers for the year, $d_{yi}$ is the duration or a total number of months for that particular year, and $i = 1, 2, 3 \ldots n$ is the number of years. The employee population, which in this formulation is 1000, can be changed to any other suitable value whereby it will indicate the incident rate for each employee population. For a better understanding, illustrations of how to calculate the yearly incident rate using the proposed method are given as follows:

For $i = 1$,

$$PIR = \frac{\left(\frac{I_{y_1}}{W_{y_1}} \times d_{y_1}\right)}{d_{y_1}} \times 1,000 \tag{5}$$

For example, in order to calculate the annual PIR, we assume the following: let a company conducts a project that is operating from August to December of a year, which is equivalent to five months in the first year. Therefore $I_{y1}$ will be the total number of incidents from August to December, while $W_{y1}$ will be the total number of workers for those five months divided by five and $d_{y1}$ is the total number of months for that year, which is equal to five. The same goes for 2-years or *n*-years of a project-based incident rate calculation. The formulation of a project-based incident rate for 2 years and *n*-years respectively are:

For $i = 2$,

$$PIR = \frac{\left(\frac{I_{y_1}}{W_{y_1}} \times d_{y_1}\right) + \left(\frac{I_{y_2}}{W_{y_2}} \times d_{y_2}\right)}{d_{y_1} + d_{y_2}} \times 1,000 \tag{6}$$

For $i = n$,

$$PIR = \frac{\left(\frac{I_{y_1}}{W_{y_1}} \times d_{y_1}\right) + \left(\frac{I_{y_2}}{W_{y_2}} \times d_{y_2}\right) + \ldots + \left(\frac{I_{y_n}}{W_{y_n}} \times d_{y_n}\right)}{d_{y_1} + d_{y_2} + \ldots + d_{y_n}} \times 1,000 \tag{7}$$

Note that, as for the monthly PIR, the same concept and calculation as in the yearly PIR are applied. At the end of the project duration, the incident rate value should be the same as that calculated using the yearly PIR formula. The main advantage of this formula is that it can be used to indicate the incident rate in any industry, especially those that do not have a fixed project duration.

## 4. Illustrative Examples

The project-based incident rate (PIR) is proposed to calculate the incident rate especially for project-based companies. This section illustrates how the PIR being used to calculate incident rate of two different companies with different project duration. The incident rate values (calculated based on Equation (4)) are then compared with the existing traditional annual IR based on employment size (calculated based on Equation (2)). An illustration on monthly PIR is also demonstrated and compared with monthly cumulative IR. Note that for many companies, the safety data are normally considered as confidential. Therefore, instead of using the real data, the illustrations given in this section are done using simulated data.

### 4.1 Yearly Project-Based Incident Rate

Yearly PIR data for two companies namely Company A and Company B are used. Let the duration of the projects be four years but the number of months between the projects are different. These two companies are project-based companies which means the project duration for both companies may not be fixed. The data for Company A is simulated such that they started the project operation on August until December for the first year, then the company continues operating for the next full two years, and during the fourth year, it only operates for a month which is in January. As for Company B, it operated fully in the first year and continued to operate for the next year, but then the company faced a problem that made them stopped operating in July of the second year. However, the company continued the project again in July of the third year until the end of December of the fourth year.

Table 1. Yearly PIR and annual IR for Company A.

| Year | No. of months per year | Average of workers | No. of incidents | Yearly PIR | Annual IR |
|---|---|---|---|---|---|
| Year 1 | 5 | 4120 | 1 | 0.24 | 0.24 |
| Year 2 | 12 | 5050 | 8 | 1.19 | 1.58 |
| Year 3 | 12 | 5957 | 5 | 1.04 | 0.84 |
| Year 4 | 1 | 6400 | 4 | 1.03 | 0.63 |

Table 2. Yearly PIR and annual IR for Company B.

| Year | No. of months per year | Average of workers | No. of incidents | Yearly PIR | Annual IR |
|---|---|---|---|---|---|
| Year 1 | 12 | 3533 | 11 | 3.11 | 3.11 |
| Year 2 | 6 | 4769 | 7 | 2.57 | 1.47 |
| Year 3 | 6 | 4835 | 0 | 1.92 | 0 |
| Year 4 | 12 | 3601 | 10 | 2.21 | 2.78 |

Based on Table 1, it can be seen that throughout the 4-year project duration, the incident rate values calculated by using the yearly PIR and the annual IR methods are almost the same where there are only small differences in the incident rate values between the two methods used. Company A has exactly the same incident rate value of 0.24 in the first year for both

methods used which means during the first 5 months, there are 0.24 workers who have injured for every 1000 workers. The same goes with the incident rate calculated for the first year for Company B where both methods give out the same incident rate values of 3.11. The incident rate value for the first year that is being calculated by the proposed method is the same as the annual IR value because there are no accumulated incident rate values from previous years. In terms of the formulation, it can be seen that the duration can be cancelled out as shown in equation (4) which makes it the same as annual IR formulation.

The difference between the methods can be seen in the following years. For the second year, the number of incidents has increased to 8 for full 12 months, and then it decreases to 5 for the following full year. Since the average number of workers for Year 2 and Year 3 are 5050 workers and 5957 workers respectively, thus by considering the duration, number of incidents and average number of workers, logically, both methods should have shown the decrease in incident rate values. However, since the proposed method is based on weighted average method, thus the incident rate values from the previous years are carried into that year's incident rate value so that an average incident rate value during the project duration can be obtained. This is why for the second year onward, the incident rates calculated by using the proposed method differs from the annual IR. The same goes with Company B.

During the fourth year, there are 4 incidents recorded in January for Company A, based on Table 1. The incident rate value calculated using the yearly PIR method shows for every 1000 workers, there are 1.03 workers who had injuries, while for annual IR, it shows that 0.63 workers have injured for each 1000 workers. The result obtained by using annual IR is said to be misleading and may not portray the real situation. This is because the company's project just started operating for a month in that year and already had four incidents, so supposedly the incident rate should be higher. Therefore, in this case, the incident rate calculated by using the proposed method seems to be more reasonable.

Based on Table 2, it can be seen that for Year 3, Company B starts to operate again on July until the end of the following year, and had an average of workers of 4835 with zero incident. Thus, the incident rate values obtained by using the yearly PIR and annual IR are 1.92 and zero respectively. As for value obtained from the PIR formulation, it shows that the amount of incident rate still exists even the incident case is zero. Also, it shows the company is getting better in term of safety performance since the previous year's incident rate is 2.57 with seven (7) incidents. However, the value evaluated by using annual IR which is zero does not really indicate that the company is success in improving their safety features, and people might think that the company's performance is in a good term. In fact in reality, it can be seen that in the following year, the incident rate drastically increased to 2.78 with ten (10) incidents that happened within the short duration. This shows how the annual IR can be misleading. The comparison between incident rate values calculated by using the yearly PIR and annual IR for both Company A and Company B are further illustrated in Figure 1 and Figure 2.

Based on Figure 1 and Figure 2, it can be seen that both methods have the same pattern of increasing and decreasing whenever there is an increase or decrease in the number of incidents. However, the incident rates calculated by using the proposed method seems to be more consistent than annual IR. There are fluctuations occurred in the incident rate values obtained by using the annual IR, and the most obvious one can be seen in Company B's incident rates calculated from Year 3 to Year 4. This is due to the drastic change in the number of incidents which is from zero incident to ten (10) incidents. Also, it can be seen that in Year 4, the incident rate calculated for Company A by using annual IR method does not really portray the real situation since the incident rate value of 0.63 is too low for a company that just started operating for a month and already had four (4) incidents happened. Thus, the incident rates obtained from the annual IR does not really reflect the actual situation throughout the whole project duration. Hence, the proposed PIR method that is based on weighted average method is more suitable to be used to calculate incident rate for project-based companies instead of

calculating the incident rate year by year solely and separately as done by the annual IR. This is because the proposed method considers other factors not only the number of incidents and the average number of workers, but also the duration of the project. Also, the proposed method is able to calculate the average incident rate per year during the whole project duration while reflecting the relative importance of each incident rate value that is being averaged.

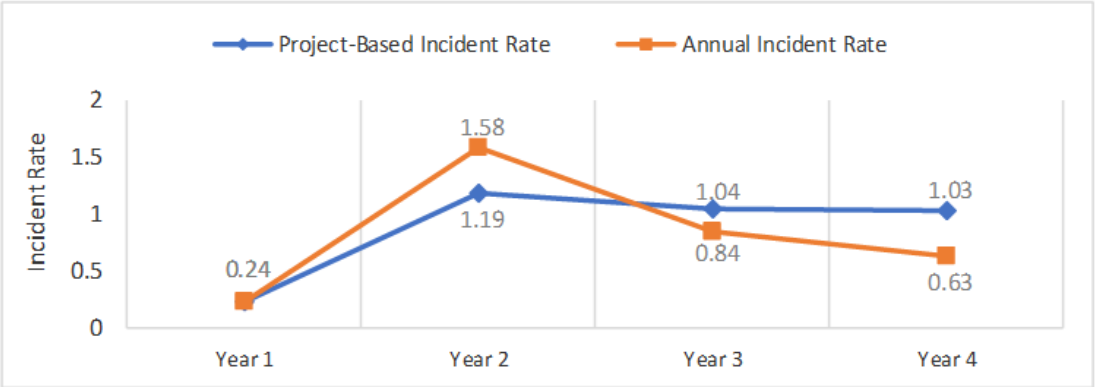


Figure 1. Comparison between yearly PIR and annual IR for Company A

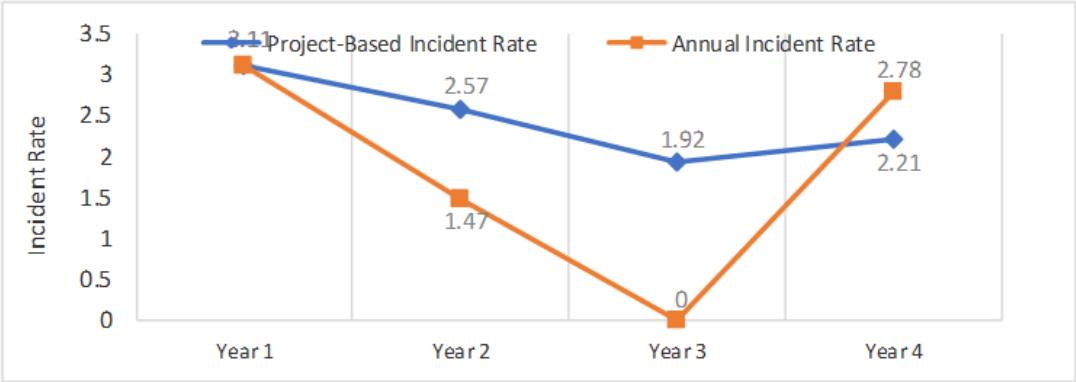


Figure 2. Comparison between yearly PIR and annual IR for Company B

### 4.2 Monthly Project-Based Incident Rate

Another advantage of the proposed PIR method is the suitability of the method to be used to calculate monthly PIR. This section gives an illustration on how the proposed method can be used to calculate monthly incident rate, and it is compared with monthly cumulative IR. The results from these two methods are then compared with annual IR to identify whether the values obtained vary greatly or not.

Basically, in order to calculate the annual IR, a company should have monthly data recorded first. In this study, instead of just calculating incident rate annually, the proposed method is also used to evaluate incident rate for each month. There are two ways to calculate monthly incident rate which are by using the same concept and calculation as in yearly PIR method, while the other one is by using continuous data. In this section, another simulated data is used for illustration purpose. Table 3 illustrates the monthly incident rate obtained by using the two methods, and then they are compared with annual IR in order to see which one is the most reasonable and reflect more on the actual situation.

Table 3 demonstrates the monthly incident rates for a three-year project duration calculated using monthly PIR method, monthly cumulative IR and annual IR with employment size of 1000. The first year starts with August and it can be seen that zero incident is recorded which means the first month has incident rate of zero for the three methods used. As stated in section 4.1, the incident rate values for the first year will be the same among the three methods since there are no accumulated incident rate values from previous years carried in the incident rate value of the first year, and this explained why at the end of the month, the incident rate values for the first year are 3.55 for all three incident rate methods used.

For the second year, the project operated for full twelve months. The monthly cumulative IR is calculated based on continuous data which means, in order to calculate the incident rate, the total number of incidents is accumulated from the first month of the first year until the current month, while the average number of workers is calculated by averaging the summation of total number of workers from the first month of the first year until the current month, by total duration in month. Also, the duration will be the number of months from the starting month until the current month. Based on Table 3, it can be seen that in Year 2 and Year 3, the monthly incident rate values are calculated by using the proposed method and the cumulative IR, differ by 2 to 13 in values approximately which is quite a lot. This is because the number of incidents, the average of workers and the duration of the project play important roles in contributing to the incident rate values. The most obvious one is on February of the Year 3 where the incident rate values calculated by using the proposed method and the cumulative IR are 7.53 and 20.64 respectively, where there are approximately 13 unit differences in value (20.64 – 7.53).

Table 3. Monthly PIR, monthly cumulative IR, and annual IR

| **Year** | **Month** | **Average number of worker** | | | **No. of incident** | **Monthly PIR** | **Monthly Cumulative IR** | **Annual IR** |
|---|---|---|---|---|---|---|---|---|
| | | **Monthly** | **Annually** | **Cumulative average** | | | | |
| Year 1 | Aug. | 498 | 563 | 498 | 0 | 0 | 0 | 3.55 |
| | Sept. | 509 | | 509 | 1 | 1.96 | 1.96 | |
| | Oct. | 536 | | 536 | 0 | 1.87 | 1.87 | |
| | Nov. | 552 | | 552 | 1 | 3.62 | 3.62 | |
| | Dec. | 563 | | 563 | 0 | 3.55 | 3.55 | |
| Year 2 | Jan. | 615 | 657 | 572 | 1 | 3.23 | 5.25 | 9.13 |
| | Feb. | 619 | | 579 | 0 | 3.00 | 5.18 | |
| | Mar. | 622 | | 585 | 0 | 2.82 | 5.13 | |
| | Apr. | 624 | | 590 | 2 | 4.11 | 8.48 | |
| | May | 628 | | 595 | 0 | 4.17 | 8.40 | |
| | June | 632 | | 600 | 0 | 4.21 | 8.33 | |
| | July | 635 | | 605 | 1 | 5.15 | 9.92 | |
| | Aug. | 638 | | 609 | 0 | 5.22 | 9.85 | |
| | Sept. | 643 | | 614 | 2 | 7.27 | 13.03 | |
| | Oct. | 648 | | 620 | 0 | 7.35 | 12.91 | |
| | Nov. | 653 | | 625 | 0 | 7.43 | 12.80 | |
| | Dec. | 657 | | 630 | 0 | 7.49 | 12.71 | |
| Year 3 | Jan. | 713 | 632 | 634 | 5 | 7.46 | 20.50 | 7.92 |
| | Feb. | 632 | | 630 | 0 | 7.53 | 20.64 | |

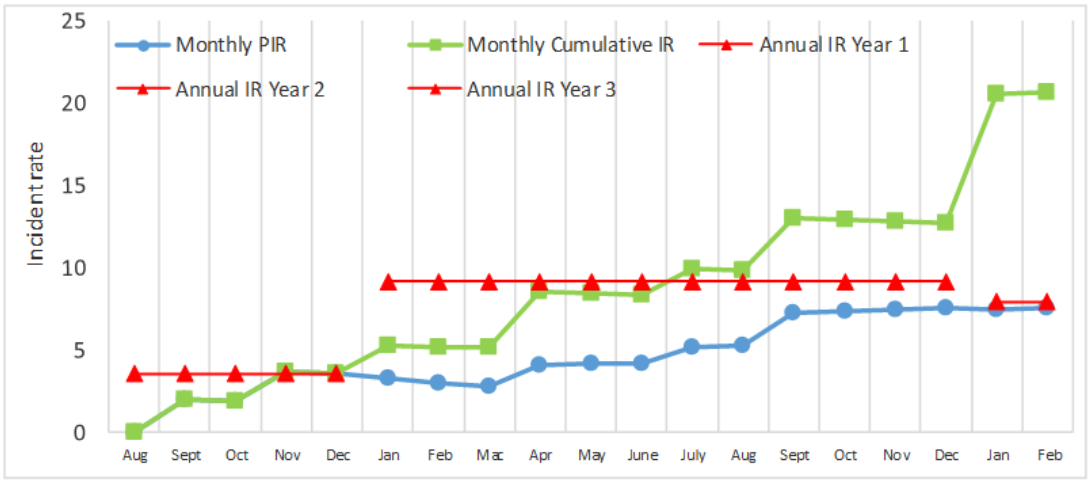


Figure 3. Graph of monthly PIR, monthly cumulative IR, and annual IR for three consecutive years

As illustrated in Table 3, it can be seen that the monthly cumulative IR increases drastically as year increases. This shows how unrealistic the incident rate values calculated based on the monthly cumulative IR. Moreover, as compared with the annual IR, the incident rate value at the end of each year calculated by using the proposed method seems to be closer and quite similar with the annual IR. This can be seen especially in Year 3 where there is only 0.39 difference in value. For further illustration, Figure 3 shows the comparison between monthly incident rate by using the monthly PIR and monthly cumulative IR, and also annual IR methods.

Based on Figure 3, it shows the incident rates changed over month. The three-line graphs represent monthly PIR, monthly cumulative IR and annual IR. Figure 3 also shows that in the first year which is from August until December, the line graph of the three methods seem to be overlapped, and started from the first month of Year 2 onward, the difference can now be seen. The incident rate values based on continuous data increased drastically to 20.64 in Year 3, while the monthly PIR smooths out fluctuations in the results and remain consistent throughout the years as it is calculated based on weighted average method. As compared with annual IR values, it can be seen that the line graph of the proposed method seems to be closer to the annual IR, than the cumulative IR. Hence, it can be said that the results obtained show that the monthly cumulative IR is not really suitable to be used to calculate incident rate as the values obtained can cause misleading in interpretation. In contrast, the proposed technique which is the PIR method can be used not only to calculate yearly incident rate, but also in obtaining monthly incident rate.

## 5. Conclusion

In this study, a project-based incident rate is proposed by utilizing the concept of a weighted average. The existing incident rate methods are formulated to calculate the incident rate annually, which means these methods might not be suitable for use with project-based industrial activities. It is suggested that the proposed method should be used for industries that operate for a specific duration, such as the construction industry. Illustrative examples based on simulated data of project-based companies were used to demonstrate how the proposed method works. The proposed method can be said to be able to better reflect the actual situation of project-based companies than the annual IR, as it gives a more reasonable evaluation. At the same time, the proposed method can be expressed both on a monthly and yearly basis. Clearly,

the proposed PIR technique can be considered to be very useful for calculating the incident rate for project-based industrial activities.

The significance of the proposed project-based incident rate is that the method can be very useful as a performance indicator. Furthermore, the proposed method could also be used for a real-time online monitoring system so that the authority can access the website to view any company's performance, whether monthly or annually. Note that it should also be possible to use the proposed method to calculate the incident rate based on the total man-hours instead of employment size.

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