ISSN (e): 2250 - 3005 || Volume, 09 || Issue, 9|| September - 2019 ||
International Journal of Computational Engineering Research (IJCER)

Statistical Moment Networking of SBT Risk Assessments

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ABSTRACT*: The current fast pace technological advancing workplace requires safety measures that are in keeping with emerging job practices. In this regard preventive approaches to hazardous situations call upon precise measurements and analysis of data for development of predictive models of safety.*
One such approach that is gaining ground worldwide is in the use of sensor based technology (SBT) which calls upon the creativity of specialists in the field of engineering and statistics to construct workplace safety networks for worker protection. The SBT approach for safety takes into account the capturing, recording and logging of data electronically using electronic sensors placed in remote locations that would otherwise be difficult to access. These data are then analysed by humans who perform statistical analyses to complete the risk assessment.
The SBT approach finds use in hostile work environments complexed with a myriad of latent hazards. One such hazard is radiofrequency propagation (r.f) which this paper uses as an example to set up the risk automated-human assessment model. The literature review reveals the application of SBT to safety while the methodology and design give the procedure for statistically analysing the collected data from the SBT sensors, thereby completing the network for the development of the automated interface risk assessment. The final risk assessment introduce a moment concept for both the pervasiveness and prevalence of the rf hazard based on hypothesis testing and a Weibull distribution model best suited to the rf data. The cdf from the Weibull is used to get both prevalence and pervasiveness predictors.
KEYWORDS*: Risk assessment, Weibull, rf propagation, sensor based technology, sensor based technology.*

Date of Submission: 27-12-2019 Date of Acceptance: 06-01-2020

I. INTRODUCTION

Risk is considered the probability of misfortune to those exposed based on some decision where there is little or no guarantee of return on investment, or, pending hazard that may pose a threat to life and limb. Good decisions require accurate information and in the absence of such there is uncertainty leading to increasing probability of losses. Once the decision is made to take the chance, there is risk and we now seek the probability of exposure to misfortune. The simple approach therefore of using subjective measures of feeling and experience in constructing a consequence and likelihood HSE risk assessment as is currently the norm in many local organizations, has no place in an advancing, complexed digital world where new manufacturing methods and human-machine interfacing have become accepted practice.
In this period of stringent resources much more will need to be done with less. This means that work must be executed smarter and the network of job duties, machinery and man will have to cooperate as never before to ensure a safe workplace. SBT (sensor based technology) is an emerging acceptable way for measuring and communicating difficult, hard-to-reach hazards that is accurate and reliable but cannot work on its own and must be supported by a network management plan with a scope ideally suited for the worksite under consideration. Radiofrequency propagation inside buildings or within bounded enclosures can be treated as a latent hazard that can be considered to need some special attention and is used as the sample report for the risk assessment so designed in this paper.

This paper sets two objectives for an automated human interface approach to risk assessments using radiofrequency wave propagation data collected at a site, as the hazard: 1) A review of the literature on the current and future use of sensor based technology (SBT) in hazard determination and information collection, recording and reporting and its suitability to risk assessments; and 2) a methodology and design for analysing the collected data using appropriate statistics to determine the prevalence and pervasiveness of the hazard for determining overall risk.

The SBT procedures offered seek to promote its use based on its simplicity, accuracy, dependability and reliability. The sensors can collect data 24 hours every day without needing a break or pay hike. This is good news for most businesses but the spin-off to this is that the technology must be supported by appropriate analysis that coincide with the data distribution pattern so collected. In this way the second objective lays claim to a more detailed way of investigating the data for a justified risk assessment of the hazard. Of course this network of SBT and human interface can be applied to other such latent, hostile hazards and pollutants in industry including, oil and gas, deep-sea exploration, explosive environments and agriculture pests and pesticides.

II. LITERATURE REVIEW

The use of SBT on construction sites is well recognised in China where heavy equipment, materials and various job skills all conglomerate causing varying complexities. SBT offers good communication, data transmission for both wired and wireless technology. Fast tracking of goods, materials and workmen is easily accomplished with its use not to mention protection from falling objects and being able to monitor moving vehicles around corners such as cranes. (Song, et al, 2006).

RFID monitoring however does not offer complete information and as such other sensor based equipment will act as support for organisational needs and these include: vision –based which uses cameras and video surveillance which may be instrumental in obtaining events that would have occurred such as worker violence and poor safety procedures. Other sensors include those for displacement and building erectness/ inclination and geological bias; pressure sensors to obtain load and capacity measurements; light sensors to monitor concrete integrity, welding jobs; nitrate sensors for testing water integrity; and optical fibre sensors to monitor long term structural safety, strains, deformation, cracks and total safety evaluation of structures as used in China (Wang et al., 2010, 2012).

Locating and positioning safety and general-use sensor-based devices may have drawbacks and advantages based on use. GPS has good accuracy in detecting faults in buildings and equipment in the open but less accuracy inside of buildings and confined spaces due to the presence of obstacles (Pradhananga, 2013).

Wireless SBTs can be placed at specific points inside and outside of plants as suggested by Taneja et al (2012) where wireless local area network (WLAN) was found to work well in all locations including external points once the wireless signal transmitters are within a coverage region of the target or hazard for faithful recording (Taneja et al, 2012). Moreover, the ultra-wideband (UWB) is an improvement on the WLAN in that it works well in the indoor monitoring and less susceptible to multipath interference (Jachimezyk et al., 2017).

The sensor-based technology model can be applied to various categories of safety and one of these is the accident forewarning system (AFS). The accident forewarning system focuses on accident prevention and control for which the technology is recommended as an early warning system capable of detecting, judging and identifying unsafe conduct and take precautionary action to prevent harm. Research in this area takes into account early warning, statistical analysis and system suitability (Zhou et al, 2013). The approach has been implemented on construction sites where two tower cranes were outfitted with RFID/SBT transmitters to report data that were analysed to determine the probability of a collision between them (Hwang, S and Liu, L, 2011). Systems have been devised for warning workers of falling objects (Carbonari et al, 2011) and drivers of impending danger due to obstacles around blind corners thereby giving real-time safety warning. (Ray et al, 2016).

Integrated safety management (ISM) applies the SBT to two aspects of safety namely: quality inspection for materials and resources, and, for management of workers' health and safety. Quality defects are believed to contribute to worker safety if workers cheat on labour or if there are long working hours and other job related issues that lead to stress. These all have the potential to affect the profits of an organisation in rework costs, and repairs.

Worker tracking is important in confined spaces such as tunnels, man-holes, mines and shafts where such monitoring falls under the heading of highly dangerous operations management (HDOM). This real time tracking can enable pinpoint trapped worker location and timely rescue which is always advantageous to reduce accidents and increase worker morale. (Lin et al 2014). Smartphones are hinted as the future for an integrated platform since they contain multiple sensors that can be applied to safety. The high popularity, low cost, portability all redound to a successful intervention (Dzeng et al., 2014).

Hospitals are work sites with an assortment of hazards that pose risks to workers, patients and visitors. Implementing a sensor based or human-detector safety device will have to take into account the problems faced before making a decision on a technology that best suits this work site. For noteworthy consideration are data integrity, where there may be conflicting data from different equipment and missing data, over alarm where the many beeps heard may cause workers to ignore them, mixing up of IV lines, patient and fluids, cleaning of tiny orifices may be difficult, software may be susceptible to privacy violations, dose creep as exposure to some hazard increases slowly and software where persons can hack the system.

Considerable interest has been paid to the use of wearable devices on plants and for patient diagnosis, treatment and management of chronic diseases. These devices, sensor-based, are attached to clothing, helmets, shoes, glasses, watches and person to also detect gas leakages in mines, low head room, changes in temperature, methane and carbon monoxide (Chan et al., 2012). Sensors therefore have emerged in importance as a first stage attack on identifying hazards and obtaining reliable readings for further analysis for a risk assessments. They are seen to have wide applications and can be useful in many industries whose hazards are difficult to address.

III. RISK PHILOSOPHY AND METHODOLOGY

Riskiness depends on an attitude to risk taking that may lead to accidents and has a connection with uncertainty that gives a divide between truth and belief, and the chance that some unwanted event occurs. A decision may be made under risk if probabilities are known but under uncertainty if such probabilities are little or unknown (Plato S, 2007). Can decisions be made under risk or under uncertainty or are they indistinguishable? A person's decision to travel to a destination by train or aeroplane may be based on his perception of the risk of a crash resulting in death. Should such risk be based on perception only or would probability be more helpful? According to HAS 2006 in their HSE guidelines: "Assessing risk means you must examine carefully what, in the workplace, could cause harm to your employees. This allows you to weigh up whether you have taken enough precautions or whether you should do more to prevent harm". This statement sums up the necessity of getting it right the first time and not doing the risk assessment subjectively.

The drawback faced when trying to get a probabilistic risk value for such a situation is fatigue, in that if the flight (above) is safe the first time it does not warrant that it is safe on another since added stress on the aircraft is now present, i.e., a hairline crack may escalate during the first flight leaving conditions for the second worse than the first and so on.

In the jargon of science and statistics we may be concerned with risks as far as they give false positive or type I error and false negative or type II error. In other words the decision is based on our belief as to whether there is a problem when there is none or whether there is no problem when there is one. Any risk assessment therefore should have its genesis in proper data collection, transmission of information and statistical analysis.

A suitable risk assessment for safety and health therefore facilitates many contributors to the design of the hazard. For organizations this may seem a hindrance to production and they must repeatedly decide whether risks are low enough. Occupational risk decisions must be taken based on pre-defined criteria that may not be suitable for all organizations but must be considered together with cultural diversity and responsibility in different workplace settings. According to Rodrigues (2012) acceptance criteria in the workplace is important and usually overlooked. To improve risk assessments therefore the subjectivity in the decision process must be reduced and tailored to each occupation (Rodrigues 2012).

In the case of measuring and monitoring latent hostile hazards such as radiowaves, pollutants, high voltage these may not be readily detected and go unnoticed until a threshold is exceeded. International standards for rf (radiofrequency) exposure set guidelines for the average person or just lower. When measuring the rf intensities however HSE operators focus on data collection and measurement that fit onto a normal distribution curve. This is understood given the large data set obtained and may at first seem to be the best fit to this parent population.

Where worker safety is concern there should be complete examination of the hazard to see if there are instances where higher than normal peaks or, maximum of maxima intensities of the hazard may occur. These are seen in the tails of the cumulative probability or probability density function (pdf) plot of the data sample and are usually ignored for simplicity. These skewed data may in fact be demonstrating a condition that begs further analysis and detailed statistical analysis of the reason and causes for their appearances.

Radiowave intensity inside bounded enclosures such as buildings, schools and offices do not die off quickly as the inverse square law dictates, Rodriguez (2018) but rather create high energy points called hot spots and low energy points called cold spots where constructive and destructive interference occurs due to intermingling of reflected and incoming waves within the walls of the bounded space. It is therefore not sufficient and adequate to measure the electric field intensity averages only in this situation but also the maximum field intensities to get the maximum of the maxima and then make a distribution model fit to determine the most likely parent population. Once this is identified a cumulative distribution function (cdf) graph can be constructed to give predicted values in the various percentile regions of exposure.

In this regard no risk assessment should only take into account averages and ignore maxima readings. In fact, the maxima readings should be the data of interest for collection and the maximum of these maxima be closely monitored for the potential risk. Based on the distribution model of choice percentile values for threshold and location intensity values can be read from the cdf and used in the design of the risk assessment.

IV. DESIGN AND PROCEDURE

A cuboid metal open at both ends of width 2.4m, height 1.2m and length 4m was constructed with metal inner walls, floor and roof. A bicolog antenna attached to a transmitter was then made to send rf waves of frequency 112MHz at an angle of approach (AOA) of 34 degrees to the front plane of the cuboid. A rf receiver was then set to maximum and the maximum readings in db at 54 different locations inside the chamber were measured and recorded, see Table 1.

Table 1. RF maxima intensities (db) at 54 locations (loc)

db	loc	db	loc	db	loc	db	loc	db	loc	db	loc
-44.5	1	-44	11	-43	21	-44	31	-45	41	-53.5	51
-80	2	-42.5	12	-44.5	22	-43.5	32	-48	42	-52	52
-62	3	-46.5	13	-44.5	23	-49	33	-46	43	-70	53
-47.5	4	-48.5	14	-40	24	-38	34	-47.5	44	-48.5	54
-47.5	5	-41.5	15	-38	25	-43	35	-48	45		
-46.5	6	-45.5	16	-43.5	26	-39.5	36	-42.5	46		
-54	7	-49	17	-40	27	-42.5	37	-51.5	47		
-55	8	-41.5	18	-42.5	28	-52.5	38	-51.5	48		
-49	9	-42	19	-45.5	29	-46.5	39	-44	49		
-41.5	10	-41	20	-46.5	30	-45.5	40	-43.5	50		

Source: Rodriguez (2018)

These data were converted to intensity in mW and plotted to obtain the cdf and pdf charts. Figure 1 shows a cumulative probability plot of the maxima intensities in db and as shown do not fall on a straight line giving kurtosis in the upper tail. This skewness is of interest since the upper tail implies intensity values above normal or extremes which may be as result of constructive interference inside the chamber and hence hot spots. This suggests that some other model distribution may give a better fit for the parent population for which software is used to match the sample distribution with various distribution models. Other models were tried for which the Weibull model gave the best fit for the distribution. Figure 3 shows the cdf chart that can be used to read off the percentiles or probabilities of getting any rf maximum intensity inside this cuboid. The cdf equations are as shown for

Weibull: f(x; α, ß) = $f(x,\alpha,\beta) = \frac{\alpha}{\beta^{\alpha}} x^{\alpha-1} e^{-(x/\beta)^{\alpha}}$, ß is the scale parameter (λ) and α is the shape parameter (k).

Table 2. Statistics values for 54 rf intensities distribution

Statistic	Value	Percentile	Value	Distribution	Parameters
Sample Size	54	Min	1.0000E-8	Frechet	□ =0.54406 □ =7.1390E-6
Range	1.5848E-4	5%	4.9822E-7	Frechet (3P)	□ =3.1136 □ =6.0258E-5 □ =-4.0058E-5
Mean	3.8694E-5	10%	4.2240E-6	Gen. Extreme Value	k=0.20203 □ =2.1346E-5 □ =2.1101E-5
Variance	1.2840E-9	25% (Q1)	1.3741E-5	Gumbel Max	□ =2.7939E-5 □ =2.2567E-5
Std. Deviation	3.5833E-5	50% (Median)	2.8184E-5	Weibull	α = 0.22135 ß = 2.5228 E-5
Coef. of Variation	0.92606	75% (Q3)	5.6234E-5	Weibull (3P)	□ =0.9429 □ =3.8599E-5 □ =1.0000E-8
Std. Error	4.8763E-6	90%	8.9716E-5		
Skewness	1.6668	95%	1.2377E-4		
Excess Kurtosis	3.1653	Max	1.5849E-4		

Source: Rodriguez (2018)

Table 2 gives the Weibull parameters of □ =0.22135and □ =2.5228E-5 in mW. The mean of the sample is 3.869 E-5 and 90 percentile is 8.9716E-4. Once a rf threshold is given, we match this value in mW on the cdf chart to find the percentile value to which it belongs. This can also be found in excel under the Weibull statistics.
The percentile for the threshold intensity is given by F(X1) = f(x1; α, ß) and gives the probability of getting a certain threshold intensity and less. This is termed the pervasiveness or how pronounced or the depth/ severity of the hazard in the sample. The percentile intensity at a location of interest termed the prevalence, is given by F(X2) = f(x2; α, ß) and is the probability of getting this intensity and less at this location inside the chamber.

The overall risk is ∏(X), where ∏(X) = [F(X2).F(X1)].

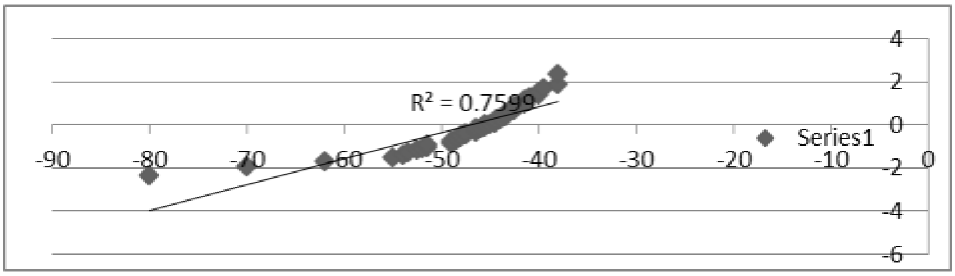


Figure 1: Max. dBm TE10 mode. Cum. prob-plot/34o/112 MHz.(Source: Rodriguez 2018)

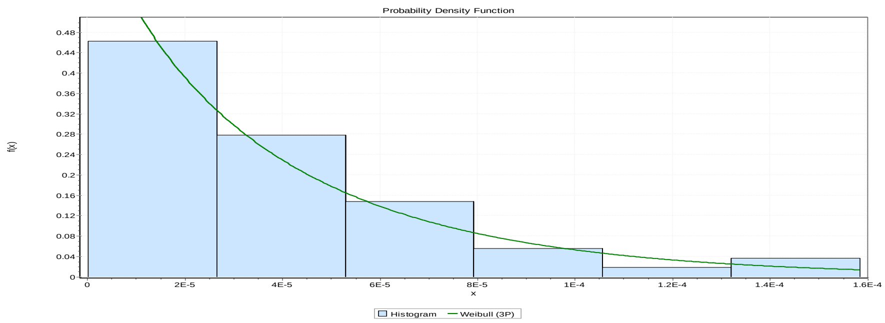


Figure 2 : PDF of Weibull Model (Source: Rodriguez 2018)

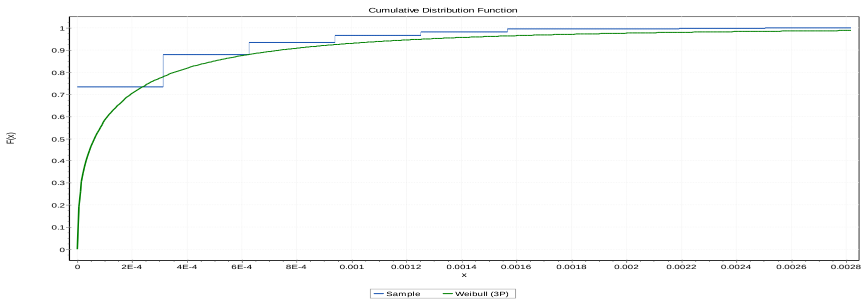


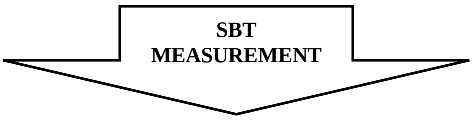
Figure 3: CDF of Weibull Model (Source: Rodriguez 2018)

V. THE RISK ASSESSMENT MODEL

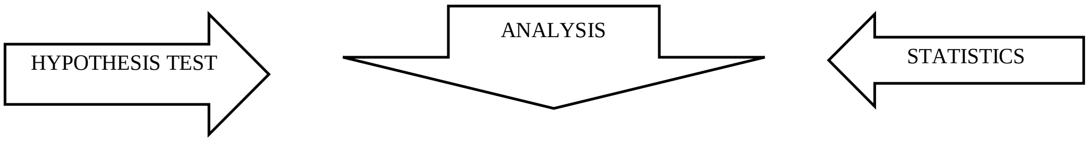
STEP 1: SBT Measurement

This step requires installation of sensors after feedback on the nature of the hazards. The sensors log the data and communicate to a central network via, wired, wireless or mobile app. Such sensors include vibration, air-quality, flood, lightening, landslip, radiation, uv light, sound and noise.

STEP 2: ANALYSIS



This step requires data management with hypothesis testing and statistical modelling.



STEP 3: RISK ASSESSMENT DOCUMENT

This step develops the prevalence and pervasiveness to give the resulting risk assessment.

Table 1 shows actual readings of field data collected from the cuboid for the 54 maxima electric field intensity data points in mW (milli-watts). The intensities at these points are the maximum intensities coming from a transmitter antenna 3m away from the entrance to a cuboid space. There is need to determine whether some of these maxima values are greater than some threshold exposure limit as a safety measure. If the average of these maxima is less than the threshold then it is not sufficient to declare a safe situation since there is uncertainty in the data and the validity of the claim must be tested. An alternate hypothesis is proposed: H_1: the sample mean came from a distribution whose population mean is less than the threshold value. The null to be tested H_0: the sample mean occurred by chance and is not a true reflection of the distribution. We test the null at the P value of 5%. Once the hypothesis is tested the next step is to test the collected data to determine whether there are outliers in the cumulative probability plot.

The sample mean µ for the data = 3.8694E-5 mW and sample standard deviation s = 3.5833E-5 mW. The threshold for r.f. of this frequency is at 3.9000E-5mW. The sample mean does in fact fall below the threshold but is it safe to say that this sample drawn did not come from a distribution whose mean is as large, or larger than the threshold and that the value obtained is just by chance?

The alternate H1: µ < 3.9000E-5 and the null H0: µ >/= 3.9000E-5 for the sample. The null hypothesis is tested at 5%. This gives Z = (3.8694 - 6.200)E-5/ 3.5833E-5 = -0.6504, which corresponds to a P value of 0.2578 or 25.78 %. The P value of 25.78% is greater than 5% so there is not sufficient evidence to reject the null in favour of the alternate based on the information given here. There is therefore some concern that a violation can occur and the risk analysis must continue.

Table 3: Maxima intensities in mW

milli watt	milli watt2	milli watt3	milli watt4	milli watt5	milli watt6
3.5481E-05	3.98107E-05	5.01187E-05	3.98107E-05	3.16228E-05	4.46684E-06
0.00000001	5.62341E-05	3.54813E-05	4.46684E-05	1.58489E-05	6.30957E-06
6.3096E-07	2.23872E-05	3.54813E-05	1.25893E-05	2.51189E-05	0.0000001
1.7783E-05	1.41254E-05	0.0001	0.000158489	1.77828E-05	1.41254E-05
1.7783E-05	7.07946E-05	0.000158489	5.01187E-05	1.58489E-05	
2.2387E-05	2.81838E-05	4.46684E-05	0.000112202	5.62341E-05	
3.9811E-06	1.25893E-05	0.0001	5.62341E-05	7.07946E-06	
3.1623E-06	7.07946E-05	5.62341E-05	5.62341E-06	7.07946E-06	
1.2589E-05	6.30957E-05	2.81838E-05	2.23872E-05	3.98107E-05	
7.0795E-05	7.94328E-05	2.23872E-05	2.81838E-05	4.46684E-05	

Table 3 gives the converted maxima intensities from db to mW. A sample of the first seven values will be analysed for the rf risk assessment.

Table 4: Risk assessment sheet with input values

Weibull equation:	$f(x,\alpha,\beta) = \frac{\alpha}{\beta^{\alpha}} x^{\alpha-1} e^{-(x/\beta)^{\alpha}}$				
Hazard: rf waves					
Threshold intensity of 3.9000mW give percentile of F(X1) = 0.66781495					
Frequency: 112MHz					
Statistics model distribution: Weibull					
alpha =0.22135mW and beta =2.5228E-5 mW					
Intensity	F(X2)	∏(X)	Risk code index	Comments	
3.5481E-05	0.66008455	0.44081433	0.1 - 1	**Red**	
0.00000001	0.15986838	0.10676249	0.01 – 0.1	**Orange**	
6.3096E-07	0.35542051	0.23735513	0.001 – 0.01	**Yellow**	
1.7783E-05	0.60344595	0.40299023	0.0001 – 0.001	**Green**	
1.7783E-05	0.60344595	0.40299023			
2.2387E-05	0.62231678	0.41559245			
3.9811E-06	0.48437159	0.32347059			
5.01E-05	0.68823131	0.45961116			
7.0795E-05	0.71602037	0.47816911			
0.00015849	0.77838531	0.51981735			

VI. DISCUSSION:

The values for F(X1) and F(X2) are obtained from the excel formula for any value of interest such as those for the ten values selected from the whole set of readings. The prevalence and overall risk are then calculated using simple excel function again. Once the hazard intensities are obtained one can simply assign the distribution function of choice to the data set and come up with the overall risk, in this case, the Weibull satisfied the rf data best. Some other distribution may be more suitable for other hazards.

Table 4 indicates the overall risk ∏(X) values which are the risks to exposure to the rf waves with a maximum of 51.981735% to a min of 10.676249%. The user of the model can set the levels for priority treatment. The risk code index gives the range of severity due to the calculated overall exposure and can be adjusted.

The limitations to this method of developing risk assessments include the difficulty in obtaining a best fit model for the data which in itself is also subjective (just what we are trying to avoid in the first place), sample size and type, data must be collected on hazards before the model can be constructed and as such is subject to method of data collection, calibration and analysis.

VII. CONCLUSION

The outcry for risk assessments that are not subjective has been identified to a minimal extent in the review but exists in organizations and other institutions. Many of these articles are readily available in company and local standards and policies. Unlike the simple consequence and likelihood variables for most risk assessments however this paper advances the importance of reliable data collection through the potential and possible use of SBT, and the support analysis for these collected data. There was however no evidence put forward to show the reliability of SBT data and the uncertainty that must accompany its readings. Two objectives were set and these were to complete a literature review for the support of SBT as a means of reliable recording of data for which hazard data are included, and, then to show a plausible approach for analysing the data collected from SBT sensors to construct a risk assessment. These two must work in tandem to achieve the result.

The focus therefore is to sensitize the reader on the importance of human and detector interaction to get desired results. There must be some level of trust between both human and machine and while we cannot reduce all error in both cases we must try to reduce where we can. There is therefore little purpose in having sophisticated SBT and poor statistical support. This support must come from human input.

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Ricardo J. Rodriguez "Statistical Moment Networking of SBT Risk Assessments" International Journal of Computational Engineering Research (IJCER), vol. 09, no.9, 2019, pp 28-35