Evaluating Performance of Projects Using Six Sigma Approach

Journal:	*Transactions on Engineering Management*
Manuscript ID	TEM-20-1015.R2
Manuscript Type:	Research Article
Keywords:	Management of quality, Project evaluations, Quality implementation, Process improvement., Manufacturing performance measurements
Subject Category:	Engineering Management, Project Management

Manuscript Title: Evaluating Performance of Projects Using Six Sigma Approach

Manuscript ID: TEM-20-1015.R2

Editor in Chief	
Comment	Response
Please note that the page limit for revisions is 42 for review articles and 38 for all other submissions (including research articles).	We have modified few sentences in the literature review a bit, some tables merged into a single table, some tables are modified, and some figures are removed so as develop the manuscript within the prescribed page limit.
In addition to the 200-250 word abstract -- a 150-200 word "managerial relevance statement" to clearly state the paper's expected contribution to practice.	Managerial relevance statement is provided in the revised manuscript.
Reviewer	
Comment	Response
I did not satisfy with using the AHP method in this paper, and my concerns are as follows: The authors mentioned that "The consistency of the pair-wise evaluation was checked and it was found to be acceptable and within the limits." I think the authors should report the value of the consistency ratio. Based on the input data in Table XI, I believe that the consistency ratio for Expert 4 is low. If the authors check the experts' opinions, there is a considerable inconsistency among them, and there are five experts only! The authors mentioned that "If we limit ourselves to simpler ranking methods, we will miss the interdependencies and may not achieve stable criteria weights [41]" Do the authors believe that their calculated weights are stable?! I should state that there are five experts in this manuscript, and the level of confidence is extremely low. For example, please see the experts' opinions regarding quality criterion. A simple sensitivity analysis can show that the weights are not stable.	The authors are thankful for this very valuable suggestion. We rechecked the calculations. Errors are now rectified. Some references, were also added. The said table is modified, based on the advice of the Editor in Chief to limit our manuscript to 38 pages. However for the quick reference of the reviewer we are providing the table here.

Pairwise comparison of criteria using Group AHP (Case 1) {this table from the earlier version is updated and summary of this table can be seen in the manuscript.}

Expert		Q	C	T	S	E	Weights	Λmax	CI	CR
Expert-1	Q	1	2	1/3	2	2	0.2097	5.20	0.051	0.046
	C	½	1	¼	1	2	0.1345			
	T	3	4	1	3	2	0.4183			
	S	1/2	1	1/3	1	1	0.1184			
	E	1/2	1/2	½	1	1	0.1191			

	Q	1	5	¼	3	2	0.2448			
	C	1/5	1	¼	1	1/2	0.0752			
Expert-2	T	4	4	1	2	3	0.4370	5.37	0.094	0.084
	S	1/3	1	½	1	1/2	0.1015			
	E	1/2	2	1/3	2	1	0.1415			
	Q	1	5	½	2	3	0.3006			
	C	1/5	1	½	1/2	1/2	0.0864			
Expert-3	T	2	2	1	3	2	0.3422	5.24	0.062	0.055
	S	1/2	2	1/3	1	1	0.1347			
	E	1/3	2	½	1	1	0.1361			
	Q	1	4	1	1	3	0.2972			
	C	1/4	1	1/3	1	1/4	0.0787			
Expert-4	T	1	3	1	4	2	0.3152	5.42	0.106	0.094
	S	1	1	¼	1	1/2	0.1241			
	E	1/3	4	½	2	1	0.1849			
	Q	1	4	2	2	2	0.3506			
	C	1/4	1	¼	1/2	1	0.0941			
Expert-5	T	1/2	4	1	2	1	0.2367	5.24	0.060	0.053
	S	1/2	2	½	1	1/2	0.1351			
	E	1/2	1	1	2	1	0.1835			
	Q	1.00	3.80	0.60	1.88	2.35	0.2851			
	C	0.26	1.00	0.30	0.75	0.65	0.0923			
Normalized Score	T	1.64	3.28	1.00	2.70	1.88	0.3440	5.06	0.016	0.014
	S	0.52	1.31	0.37	1.00	0.65	0.1236			
	E	0.42	1.51	0.52	1.51	1.00	0.1551			

Legend Q: Quality, C:Cost, T:Time, S: Security, E: Environment

Pairwise comparison of criteria using Group AHP (Case 2) {this table from the earlier version is updated and summary of this table can be seen in the manuscript. }

Expert		Q	C	T	S	E	Weights	λmax	CI	CR
	Q	1	1	5	1/3	1/2	0.14911			
	C	1	1	3	1/5	2	0.15994			
Expert-1	T	1/5	1/3	1	1/9	1/2	0.04902			
	S	3	5	9	1	3	0.49278			
	E	2	1/2	2	1/3	1	0.14916	5.32	0.081	0.072
	Q	1	2	3	¼	2	0.20661			
	C	½	1	4	½	1	0.15959			
Expert-2	T	1/3	1/4	1	1/5	1/4	0.05418			
	S	4	2	5	1	3	0.43365			
	E	½	1	4	1/3	1	0.14597	5.27	0.068	0.061
	Q	1	1	3	1/5	1	0.15196			
Expert-3	C	1	1	3	½	2	0.20188			
	T	1/3	1/3	1	1/6	1	0.07552			
	S	5	2	6	1	2	0.44135	5.24	0.062	0.055

	E	1	1/2	1	½	1	0.12929			
Expert-4	Q	1	2	4	1	1	0.25794			
	C	½	1	1	1/4	1/4	0.08572			
	T	¼	1	1	1/4	1/4	0.07293			
	S	1	4	4	1	1	0.29171			
	E	1	4	4	1	1	0.29171	5.05	0.014	0.013
Expert-5	Q	1	1	1	1/2	2	0.17432			
	C	1	1	1/3	1/2	4	0.16922			
	T	1	3	1	1	2	0.26808			
	S	2	2	1	1	5	0.31220			
	E	½	1/4	1/2	1/5	1	0.07618	5.27	0.069	0.062
Normalized Score	Q	1.00	1.31	2.82	0.38	1.14	0.19402			
	C	0.75	1.00	1.63	0.36	1.31	0.15763			
	T	0.35	0.60	1.00	0.24	0.57	0.08717			
	S	2.60	2.75	4.04	1.00	2.45	0.41102			
	E	0.87	0.75	1.74	0.40	1.00	0.15016	5.043	0.01	0.009

Legend Q: Quality, C: Cost, T:Time, S: Security, E: Environment

Evaluating Performance of Projects Using Six Sigma Approach

Abstract

Researchers have attempted to improve the project performance using principles like lean, just-in-time, total quality management, etc. However, little research is done to quantitatively assess project performance by using six sigma metrics. In this manuscript, we present weighted Rolled Throughput Yield (RTY), and hence six sigma, based methodology to evaluate the performance of projects, considering multiple criteria. Here, we consider a project decomposed into work breakdown structure of multiple levels. This approach considers seven criteria, classified under five groups namely, quality, cost, time, safety and environmental sustainability for evaluating the performance. Analytical Hierarchy Process (AHP) is used to assign weights to the criteria. RTY obtained is converted into a sigma value. The results are relevant from practical point of view since we consider various elements for performance evaluation, namely, a) complex series-parallel structure of processes in a project; b) hierarchical structure of the project; c) multiple criteria for Sigma Level (SL) computation; d) performance based on "correct first time" concept; e) flexible approach enabling the manager to add/delete the criteria depending on the need. We explain the developed methodology using two practical case studies. This is the first time that the particular six sigma metric is applied to assess the performance of construction and innovation projects. This approach is simple, lucid, yet effective, and we hope it will be useful to researchers and practicing managers alike.

Managerial Relevance Statement

Many projects face critical delays, excess costs, reduced quality, local environment and safety concerns at its various stages. Further, the current performance measurements have limited multidimensional and hierarchical evaluation of projects. To overcome these challenges, we present an approach that provides a systematic framework to decision makers. This approach helps locate loopholes while maintaining top-level priority goal towards yield improvement of overall project. It is suggested that giving greater attention to Sigma Level (SL) approach may help improve customer satisfaction, reduce operating costs, and achieve expected quality of the projects.

The output of this research can be applied to measure the performance of complex process improvement projects (e.g: Six Sigma / LSS projects) in construction industry, manufacturing organizations and service sector. We explicitly illustrate an application of the methodology developed in an innovation and a construction project.

Keywords: Rolled Throughput Yield; Six Sigma; Project performance; Construction; AHP

1. Introduction

It has been widely recognized that the application of six sigma and quality management has significantly improved the performance in organizations [1]. The six sigma methodology is also integrated with lean principles and Quality Management practices for evaluating performance of various improvement projects [2-5]. However, practitioners have argued that six sigma has just repackaged traditional quality management practices[6] but the study by Zu *et al.* [1] revealed that three new practices are critical for implementing six sigma concept and method in organization. These practices are six sigma role structure, six sigma structured improvement procedure, and six sigma focus on metrics.

Six sigma has a significant impact on decision making while conducting improvement projects. One of the important metrics of six sigma in the study of performance evaluation and in quality management is Rolled Throughput Yield (RTY) [7]. RTY is a useful metric as it evaluates the performance considering scrap, rework, customer satisfaction and warranty. RTY is computed for processes to find the probability that the unit passes through the processes defect free for the first time. RTY's use in construction projects would be helpful in reducing problems of quality [2], where there is a scope for improvement in the approach, in light of a complex work breakdown structure (WBS) in projects. Here, the complexity of WBS and project is a measure based on the number and variety of components, their interdependencies, structure (series and/or parallel) and various levels [8]. RTY, derived from a term First Pass Yield (FPY), indicates the ratio of number of good units (without scrap and rework) coming out of the process to the total input. RTY's applicability in manufacturing sector is well-established [9-10]. Also, the applicability of RTY has been extended to supply chains' performance assessment [11]. In this paper, we propose an analytical model using RTY to compute performance of projects. The use of RTY is still restricted within organizations and there is scope to explore the inter-organizational setting [8]. Typically, projects involve multiple organizations working together to achieve common goal. More specifically, the literature has not yet addressed the performance evaluation of projects considering the application of six sigma techniques such as RTY. Here, we address the following research questions, based on the gap/s in extant literature to make few contributions to literature on RTY:

- How can project performance be analytically modelled using six sigma metrics?
- How do six sigma metrics address the hierarchical and complex series-parallel structure of processes in projects?
- How should managers compute overall Sigma Level (SL) of projects using multiple criteria?

In this work, we consider a project network comprising of a complex structure, where the activities are considered to be in a combination of series and parallel structure. After obtaining the relationship between individual entities, we can identify the activities at each of the levels (*1* through *n*) such as project, component, sub component, work package, etc., occurring in series and in parallel. For our study, we considered a total of seven criteria, classified under five groups namely, quality, cost, time, safety, and environment sustainability to compute the overall project performance. While the criteria considered are not exhaustive, they may be added or reduced depending on the need for a specific project [12]. For example, some other important criteria such as serviceability, team satisfaction and client satisfaction for service projects and aesthetics, ease of use and reliability, etc. for entrepreneurial projects can be added in the project evaluation.

This is a bottom-up approach for performance evaluation for projects, therefore, once we are able to compute the FPY for each of the lowermost level in break down structure, and for each of the criterion mentioned, we compute the overall RTY at this level. Subsequently, we compute the RTY for higher levels and hence the project. The method is simple and effective, and it would be relevant for construction projects, innovation projects, service industry projects, process monitoring, defect free production and overall quality assessment.

In the next section, we look at the relevant literature. The third section of this manuscript explains various criteria considered and their specific approaches to compute RTY and hence SL. Fourth section explains the proposed methodology. In the fifth section, we present cases of an innovation project for consumer durables organization and of railway line construction project. In the sixth section, we present the managerial implications for applications. Finally, we present the conclusions and suggest further developments in the proposed approach.

2. Literature Review

RTY as a performance evaluation tool drives the improvement in the system by addressing the yield of processes/sub-process. However, the effectiveness of RTY is reflected majorly in manufacturing industry and supply chains [9-11]. Graves [7] presented the concept of RTY and explained its use for process monitoring in a manufacturing process of telephone equipment. The author stated that reduction in defects improves RTY, which subsequently improves the annual savings in the organization. Park *et al.* [9] applied the RTY improvement plan to an automotive steering wheel manufacturing process in Korea. Hwang [10] posited that incorporating manufacturing execution system (MES) would improve the process capability including RTY. Dasgupta [11] broadened the applicability of RTY and other six sigma metrics to supply chains and its entities. The framework was applied to an organization having retail outlets, field offices, processing unit, branch offices. Similarly, Saghaei *et al.* [13] applied a model on supply chains of textile industry. They used a mixed integer non-linear model to measure RTY improvement. Saghaei *et al.* [14] applied an enhanced approach of RTY to an electronics industry to address the difference between scrap and rework cycles. Thus, we can see that the applicability of RTY in manufacturing and supply chain is well illustrated in literature.

There are authors who used RTY in domains, which were less explored using six sigma. For example, Eissa *et al.* [15] assessed the performance of water treatment plant, which produced purified water for drug pharmaceutical manufacturing. Zhao *et al.* [16] assessed the mental workload due to complexity of products an assembly line. The authors stated that incorporating mental workload can improve the performance by enhancing the RTY and efficiency. Koziolek and Derlukiewicz [17] impact of defects on quality of the construction process while developing a new high quality product. They analysed the process and implemented RTY to analyse structural defects, manufacturing defects etc.

RTY utilizes quality as the criteria for evaluating the performance. Yet, there are other criteria, which can be used for performance evaluation. Ravichandran [18] included cost based process weights to calculate weighted DPMO and overall SL. Ruben *et al.* [19] applied the lean six sigma framework to Indian automotive component industry by considering environmental factors. Vaidya [20] evaluated the on time performance for a class of Indian railways (using RTY), where the data was found out to be unruly. Larsen *et al.* [21] analyzed the factors that affect frequent time and cost overruns and reduced quality of construction projects. As addressed by

Antony and Banuelas [22], the proper criteria selection can help in identification of critical success factors (CSFs) for implementation of six sigma.

Here, we briefly explain relevant approaches of SL computations using RTY. RTY is derived from First Pass Yield (FPY). FPY, also referred to as Throughput Yield or First Time Yield, follows the traditional concept of process yield [23]. FPY accounts for the rework and hence rework is not counted as the output, rather it is considered as a defect. Another way of measuring FPY is by determining the Defect per Unit (DPU) for the process. Rolled Throughput Yield (RTY) is the product of all throughput yields for all steps in the process. Normalized rolled throughput yield is an average of FPY. Pyzdek [24] provided RTY and NRTY and computed "organization" SL to measure overall system quality. Supply Chain rolled throughput yield as presented by Dasgupta [11] and Saghaei *et al.* [13] use the traditional approach to calculate RTY for a supply chain network by considering the sequential and parallel chain of activities. Here, the RTY is calculated by finding the product of yields for individual entities. Ravichandran [25] provided a weight based SL computation by assigning weights to defects per million *(dpm)* where *dpm* are considered equally likely.

As highlighted by Williams [26], major projects within defence, construction and oil industries were prone to uncertainties. The author stated a need for quantification of project risks. Similarly, Keil *et al.* [27] highlighted that service projects like software development are frequently prone to escalation. Bailetti *et al.* [28] stated that complexity and uncertainty of projects hinder the applicability of WBS, and activity based management tools. Later, WBS was used effectively in complex projects for evaluating various parameters [29-31]. However, so far this approach has not been extended to measure the performance using six sigma metrics. Hence, there is a need to develop a new approach to compute RTY, given a complex network structure, i.e. a structure composed of number of series and parallel paths. Computation of RTY will help an evaluator to comprehend the performance of the project, in terms of how good the project is when executed for the first time. This will help the analyst improve the performance on various fronts, like cost, time, environment friendliness etc. An attempt is made to compute the RTY in this regard with respect to various dimensions. After computing the RTY, we can easily convert this number to a SL value, using a SL conversion chart. This will further help understand processes as compared to the standards. This not only improves the understanding of the process, but also helps in taking appropriate actions to improve it even further. Secondly, even though RTY has been integral part of measuring performance of the system, its use for project performance is still limited. In this paper, we illustrate an extension of RTY to measure the performance of projects, using two case studies. The first case is of innovation project in consumer durables organization, and the second case is of railway track construction project in a mining company.

3. Criteria and Yield Computations

We now present some of the popularly used expressions in computing Yield [24]. Number of reworks and rejects play an important role to measure the quality of projects, which impact the schedule as well as overall cost [32].

$$DPMO = \frac{Total\ number\ of\ defects * 1{,}000{,}000}{Total\ number\ of\ opportunities} = \frac{D * 1{,}000{,}000}{TOP}$$

$$Process\ Yield = \frac{Output}{Input} * 100\%$$

$$FPY = \frac{Output - Rework}{Input} * 100\%$$

$FPY = e^{-DPU} \approx$ 1-DPU, if DPU is very less.

$$RTY = \prod_{j=1}^{K} FPY_j = \prod_{j=1}^{K}\left(1 - \frac{DPMO_j}{10^6}\right) \quad (1)$$

where FPY_j is the FPY for the sub process *j*, i.e. proportion of units good at step *j* in a multistep process, $DPMO_j$ is defects per million opportunities for the sub process *j*.

$$NRTY = \sqrt[K]{\prod_{j=1}^{K} FPY_j} \quad (2)$$

$$RTY_{Supply\ Chain} = \prod_i \prod_j Y_{ij} \quad (3)$$

Project managers have to carefully analyze a tradeoff between time, cost and quality [33]. For projects, typically manufacturing, some more criteria, namely, safety and environment sustainability etc. can also be considered [34-35]. We compute RTY and hence SL for these five criteria, namely, quality, cost, time, safety and environment sustainability.

In order to comprehend our approach better, we provide an illustration of a hypothetical example as follows, considering the activities A, B, C and D (arranged in series and parallel combination) in a project as shown (Figure 1). This illustration helps understand the RTY computations at the bottom most level of the project with respect to the criteria used for comparison.

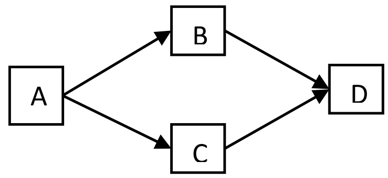

Figure 1. Project network (illustration)

3.1 Quality

RTY for quality is found through the conventional method of yield by looking into the total output for the activity and the total input for the activity (Table I).

$$FPY_k = \frac{Total\ Output_k}{Total\ input_k} = \frac{TO_k}{(RW_k + RJ_k + AI_k)}$$

$$RTY_{quality} = \begin{cases} \left(\prod_{i=1}^{m} p_{a_i}\right)_{quality} & \forall\ activity\ i\ in\ series \\ \left(\sum_{j=1}^{n} w_j p_{b_j}\right)_{quality} & \forall\ activity\ j\ in\ parallel \end{cases}$$

where TO_k is the total output items of activity k, TI_k is the total input items of activity k. RW_k is the number of reworks of activity k, RJ_k is the number of rejects of activity k, AI_k is the actual input items of activity k, p_{a_i} is the FPY of activity *i* in series, p_{bj} is the FPY of activity *j* in parallel, w_j is the weight associated with activity *j* in parallel. Here for illustration, we assume equal weight (w_j) = ½ between activity B and C for all criteria.

3.2 Cost

RTY for cost is found by looking into the budgeted cost for the activity and the total cost for the activity (Table I). Total cost comprise of actual cost of activity, rework cost and reject cost.

$$FPY_k = \frac{BC_k}{AC_k} = \frac{BC_k}{(RWC_k + RJC_k + MC_k)} \quad \forall\ BC_k < AC_k$$

$$FPY_k = 1 \quad \forall\ BC_k \geq AC_k$$

$$RTY_{cost} = \begin{cases} \left(\prod_{i=1}^{m} p_{a_i}\right)_{cost} & \forall\ activity\ i\ in\ series \\ \left(\sum_{j=1}^{n} w_j p_{b_j}\right)_{cost} & \forall\ activity\ j\ in\ parallel \end{cases}$$

where FPY_k is the FPY of activity k, BC_k is the budgeted manufacturing cost of activity k, RWC_k is the rework cost of activity k, RJC_k is the reject cost of activity k, MC_k is the manufacturing cost of activity *k*, AC_k is the actual total cost of activity *k*, p_{a_i} is the FPY of activity *i* in series, p_{bj} is the FPY of activity *j* in parallel.

TABLE I. RTY calculations for quality and cost

RTY Calculations (Quality)						**RTY Calculations (Cost)**					
Activity	**AI**	**RW**	**RJ**	**TO**	**FPY**	**BC**	**AC**	**RWC**	**RJC**	**Total Cost**	**FPY**
A	100	1	2	97	1	11000	10000	1180	900	12080	0.9
B	98	1	3	94	0.9	9000	7000	1674	110	8744	1
C	95	0	0	95	1	4000	4200	941	650	5691	0.7
D	95	4	0	91	0.9	1500	1000	200	120	1320	1

$RTY_{quality}$ = 0.97*(1/2*0.94+1/2*1)*0.92 = 0.87, $SL_{quality}$ = 2.65

RTY_{cost} = 0.91*(1/2*1+1/2*0.71)*1 = 0.78, SL_{cost} = 2.3

3.3 Time

RTY for time is found by looking into the expected time for the activity and the total time for the activity (Table II). Total time comprise of actual time of activity and wasted time due to rework and reject.

$$FPY_k = \frac{ET_k}{TT_k} = \frac{ET_k}{(AT_k + WT_k)} \qquad \forall ET_k < TT_k$$

$$FPY_k = 1 \qquad \forall ET_k \geq TT_k$$

$$RTY_{time} = \begin{cases} \left(\prod_{i=1}^{m} p_{a_i}\right)_{time} & \forall\ activity\ i\ \ in\ series \\ \left(\sum_{j=1}^{n} w_j p_{b_j}\right)_{time} & \forall\ activity\ j\ in\ parallel \end{cases}$$

where ET_k is the expected time of activity *k*, TT_k is the total time of activity *k*, AT_k is the actual time of activity *k*, WT_k is the time wasted due to rework and reject of activity *k*, p_{a_i} is the FPY of activity *i* in series, p_{bj} is the FPY of activity *j* in parallel.

3.4 Safety

RTY for safety is computed by following the approach suggested by Sanni-Anibire *et al.* [34] and finding the Risk priority number(RPN) and Risk rating(RR) for each activity(Table II).

$$RPN_k = HC_k * I_k * F_k$$

$$ARPN_k = \frac{RPN_k}{\max_k RPN_k} * 100$$

$$RR_k \epsilon\ (0,1,2,3,4)$$

$$FPY_k = \left(1 - \frac{RR_k * ARPN_k}{100 * k}\right) = (1 - \frac{ARR_k}{100})$$

$$RTY_{safety} = \begin{cases} \left(\prod_{i=1}^{m} p_{a_i}\right)_{safety} & \forall\ activity\ i\ \ in\ series \\ \left(\sum_{j=1}^{n} w_j p_{b_j}\right)_{safety} & \forall\ activity\ j\ in\ parallel \end{cases}$$

Where HC_k is the hazard criticality of activity *k*, I_k is the severity of occurrence of safety risk(impact) in activity *k*, F_k is the frequency of occurrence of safety risk in activity *k*. RPN_k is the risk priority number of activity *k*, $ARPN_k$ is the adjusted risk priority number of activity *k* found by normalizing RPN_k, RR_k is the risk rating of activity *k*, ARR_k is the adjusted risk rating of activity *k*, RTY_{safety} is the RTY for safety for network.

Table II. RTY calculations for Time and safety

	RTY Calculations (Time)					**RTY Calculations (Safety)**							
Activity	ET	AT	WT	Total Time	FPY	HC	I	F	RPN	ARPN	RR	ARR	FPY
A	3	3.2	1	4.2	0.71	0.42	3	4	5.04	97.67	2	48.83	0.52
B	9	8.5	0.7	9.2	0.98	0.3	1	2	0.6	11.62	0	0	1
C	4	4.5	0.2	4.7	0.85	0.21	5	1	1.05	20.35	4	20.35	0.79
D	5	4	0.5	4.5	1	0.43	2	6	5.16	100	1	25	0.75

RTY_{time} = 0.71*(1/2*0.98+1/2*0.85)*1 = 0.65, SL_{time} = 1.9

RTY_{safety} = 0.52*(1/2*1+1/2*0.79)*0.75 = 0.35, SL_{safety} = 1.1

3.5 Environment Sustainability

RTY for environment sustainability is computed by looking into three measures: air pollution through air quality measure, noise level and waste generation. According to Shokri *et al.* [35], there needs to be a holistic evidence of sustainable implementation of six sigma projects. Therefore, we evaluate the environmental impact of projects using three independent measures. We find the overall weighted environment sustainability RTY. We assign these weights using Analytic Hierarchy Process (AHP) for three measures.

The standard air quality measure is found by averaging the standard values of particulate matter PM10, PM2.5, Sulphur dioxide, oxide of nitrogen, and carbon monoxide limits. For industrial areas in India this value is 50 while for ecologically sensitive areas this value is 40.

$$FPY_k = \frac{SAQ_k}{OAQ_k}\ \ \forall\, SAQ_k \leq\ OAQ_k$$

$FPY_k = 1 \qquad \forall\, SAQ_k > OAQ_k$

$$RTY_{air\ quality} = \begin{cases} \left(\prod_{i=1}^{m} p_{a_i}\right)_{air\ quality} & \forall\ activity\ i\ \ in\ series \\ \left(\sum_{j=1}^{n} w_j p_{b_j}\right)_{air\ quality} & \forall\ activity\ j\ in\ parallel \end{cases}$$

where FPY_k is the FPY of activity k, SAQ_k is the standard air quality of activity k, OAQ_k is the observed air quality of activity k, $RTY_{air\ quality}$ is the RTY for air quality for network.

For noise level, we find the standard noise level and observed noise level. The Indian standard value for industrial areas during daytime is 75 and for residential areas, this value is 55.

$FPY_k = \frac{SNL_k}{ONL_k} \quad \forall\, SNL_k \le ONL_k$

$FPY_k = 1 \qquad \forall\, SNL_k > ONL_k$

$$RTY_{noise} = \begin{cases} \left(\prod_{i=1}^{m} p_{a_i}\right)_{noise} & \forall\ activity\ i\ is\ in\ series \\ \left(\sum_{j=1}^{n} w_j p_{b_j}\right)_{noise} & \forall\ activity\ j\ is\ in\ parallel \end{cases}$$

where FPY_k is the FPY of activity k, SNL_k is the standard noise level of activity k, ONL_k is the observed noise level of activity k, RTY_{noise} is the RTY for noise pollution for network.

Similarly, for construction wastes such as asphalt, concrete chunks, surplus soil and construction scrap material, we look into waste utilization through recycling and reuse to measure the FPY for each activity.

$FPY_k = \%WU_K = \frac{WU_k}{WG_k}$

$$RTY_{waste} = \begin{cases} \left(\prod_{i=1}^{m} p_{a_i}\right)_{waste} & \forall\ activity\ i\ is\ in\ series \\ \left(\sum_{j=1}^{n} w_j p_{b_j}\right)_{waste} & \forall\ activity\ j\ is\ in\ parallel \end{cases}$$

where FPY_k is the FPY of activity k, $\%WU_k$ is the percent waste utilized during activity k, WU_k is the waste utilized during activity k, WG_k is the waste generated during activity k. Waste is measured in metric ton per time period.

Once RTY for air quality measure, noise level and waste generation are found (Table III), we find the RTY for environment sustainability by multiplying the weights (from AHP) with respective RTYs. For this illustration, however, we are considering the equal weights of 0.333 each.

$RTY_{environment} = \sum_{i=1}^{3} w_i\, RTY_i$

Table III. RTY calculations for air quality, noise and waste

Activity	SAQ	OAQ	$(FPY)_{AQ}$	SNL	ONL	$(FPY)_{NL}$	WG	WU	$(FPY)_{W}$
A	50	52	0.97	75	81	0.93	930	830	0.89
B	50	53	0.94	75	62	1	120	100	0.83
C	50	44	1	55	47	1	360	330	0.92
D	50	54	0.92	75	84	0.89	270	270	1

$RTY_{air\ quality}$ = 0.97*(1/2*0.94+1/2*1)*0.92= 0.87, $SL_{air\ quality}$ = 2.65

RTY_{noise} = 0.93*(1/2*1+1/2*1)*0.89= 0.83, SL_{noise} = 2.45

RTY_{waste} = 0.89*(1/2*0.83+1/2*0.92)*1= 0.79, SL_{waste} = 2.3

Therefore, $RTY_{environment}$ = (0.33*0.87) + (0.33*0.83) + (0.33*0.79) = 0.822

$SL_{environment}$ = 2.45

4. Proposed methodology for a Project Network

In this section, we present the proposed methodology to compute the RTY of the project and hence SL. A complex project network is considered that has activities in a combination of series and parallel structure. The following generalised formulae are used to compute the RTY values.

$$RTY_{network} = \begin{cases} \left(\prod_{i=1}^{m} p_{a_i}\right) & \forall\ activity\ i\ is\ in\ series \\ \left(\sum_{j=1}^{n} w_j p_{b_j}\right) & \forall\ activity\ j\ is\ in\ parallel \end{cases} \tag{4}$$

Where m is the number of activities in series,

n is the number of activities in parallel,

p_{a_i} is the FPY of activity i in series,

p_{bj} is the FPY of activity j in parallel,

w_j is the weight associated with activity j in parallel.

DPMO using RTY is computed as (1-RTY)x10^6, later SL is computed using the conversion table [24]. The research flowchart for calculating SL for the project is shown in Figure 2. We start with the work packages, check for the activities in series, and parallel while making the decision for specific RTY calculation. The specific steps of the flowchart are detailed in the following analysis of proposed methodology.

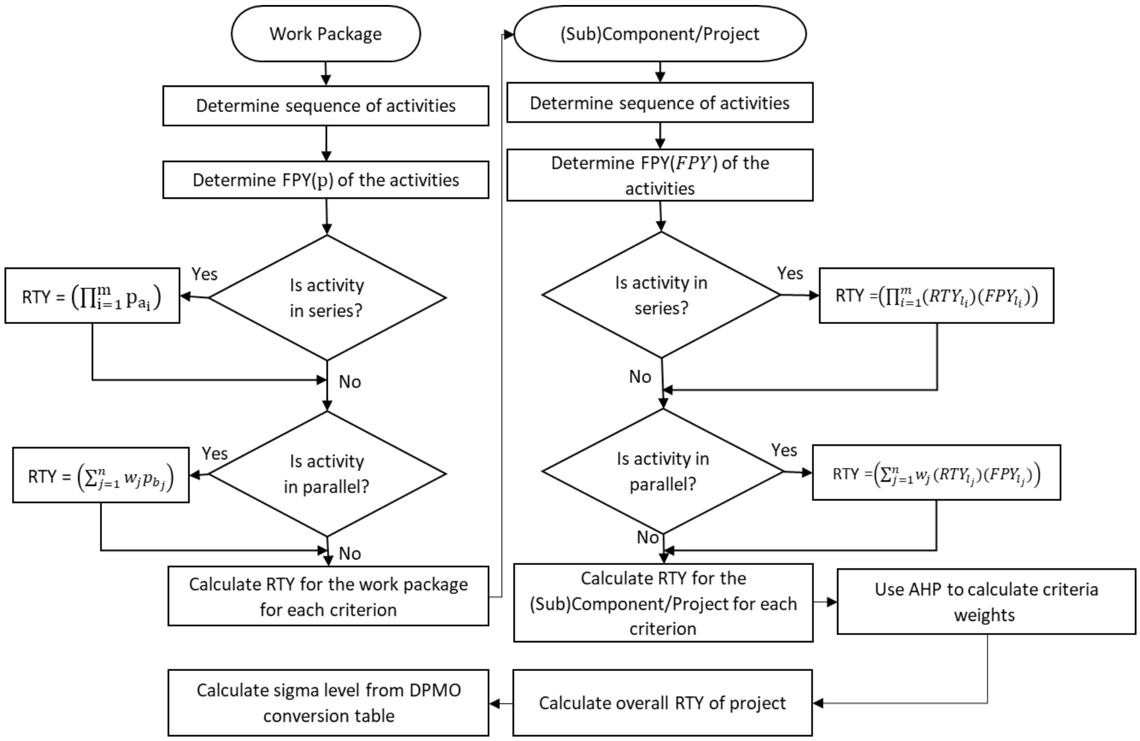

Figure 2. Flowchart for RTY and SL computation

4.1 Assumptions of proposed methodology

Few assumptions are mentioned as follows:

i. All the activities in the project are finish to start type with lag = 0.

ii. The number of opportunities, at each activity is equal to one, therefore, defects per unit is equal to defects per opportunity.

4.2 Proposed Methodology

Step 0: Determine the sequence of activities in the project. Identify the parallel and series activities. Draw a precedence diagram. Initially, begin with the lowest possible level and subsequently move to the higher level.

Step 1: Determine the FPYs of each of the activities.

Find the FPY of all the activities by considering all criteria as shown in section 3. Note that the output of an activity is the input of next activity.

Step 2: For each criteria, compute the RTY for the lowermost level after assigning weights to the activities in parallel. Weights can be assigned considering:

- The time spend by a task at an activity with respect to the total time spent in the system.

- The number of activities to be performed after this activity under consideration.
- The importance of this activity in the system.

Similarly, we compute RTY for all other criteria.

Step 3: Considering the values computed in step 2, move to the higher level. The RTYs of activities of a lower level are combined to find the RTY of the immediate higher level. This step is repeated for each level; and within each level for each criterion under consideration. We use the following expressions 5.

$$RTY_{nl} = \begin{cases} \left(\prod_{i=1}^{m} (RTY_{l_i})(FPY_{l_i})\right) & \forall\ work\ package\ i\ is\ in\ series \\ \left(\sum_{j=1}^{n} w_j (RTY_{l_j})(FPY_{l_j})\right) & \forall\ work\ package\ j\ is\ in\ parallel \end{cases}$$

Where l is given level, nl is next higher level (5)

Step 4: Finally, the RTY is calculated for the entire project. RTY_c is multiplied with FPY_c in series and parallel respectively to find RTY of project for each of the five criteria.

$$RTY_{project} = \begin{cases} \left(\prod_{i=1}^{m} (RTY_{c_i})(FPY_{c_i})\right) & \forall\ component\ i\ is\ in\ series \\ \left(\sum_{j=1}^{n} w_j (RTY_{c_j})(FPY_{c_j})\right) & \forall\ component\ j\ is\ in\ parallel \end{cases} \quad (6)$$

Where, c is the immediate lower level of project

m is the number of activities in series,

n is the number of activities in parallel,

FPY_{ci} and FPY_{cj} are the FPY of activities in series and parallel respectively,

$W_j$is the weight associated with parallel activity,

Step 5: Once the RTY and weights of the criteria (obtained through AHP) are known for the penultimate stage (immediate lower level) of the project, the SL for respective criteria and overall SL for the project is computed using DPMO six sigma conversion table. Compute the DPMO for project ($DPMO_p$) by multiplying the weights with DPMO computed for respective criteria.

$$DPMO_i = (1 - RTY_i) * 10^6 \quad (7)$$

$$DPMO_p = \sum_{i=1}^{u} w_i DPMO_i \quad (8)$$

Where, $w_i$is the weight of specific criteria obtained from AHP, u is the total number of criteria and $DPMO_i$ is the DPMO for criteria i.

4.3 A note on determination of criteria weights

The group of 5 experts; project managers (two), senior executive in the organization (one), and academicians i.e. professor and associate professor (two), was constituted. The experts identified the criteria, which were essential for evaluating the overall performance of the project. Group Analytic Hierarchy Process was used to assign criteria and sub-criteria weights.

The decision problem is divided into a hierarchy of sub-problems, each of which can be analyzed independently. Once the hierarchy is built, a numerical scale by Saaty [36], Vaidya and Kumar [37] is assigned to the pair of n alternatives(A_i, A_j) . The pairwise comparison is made by experts among the alternatives with respect to the impact of the alternative to the element in the superior level of hierarchy. The overall expert judgements are created and computed using geometric mean approach to AHP [38-39]. The geometric mean approach is adopted in order to preserve reciprocal property [40]. The consistency of the pair-wise evaluation was checked and it was found to be acceptable and within the limits.

AHP is relevant in the current problem since direct and personal involvement of decision maker (DM) is necessary. We can apply pairwise comparisons using AHP as there is no existing relationships among the selected criteria. Further, personal considerations and judgements of DMs need to be quantified in an objective manner; hence, we use AHP. The advantage of using group AHP is that the importance given to criteria weights takes into consideration DMs in the inter-organizational setting. If we limit ourselves to simpler ranking methods, we will miss the interdependencies and may not achieve stable criteria weights [41]. However, when problems far exceed DMs responsibilities due to multiple relationships and unique characteristics of complex scenarios, AHP may not be correct method [42]. Further, when number of criteria are very high, it would be essential to incorporate other methods. In the present situation, we infer that AHP or group AHP are best suited to find criteria weights.

5. Case Studies

In this section we present two case studies, a) new product development and b) railway track construction for mining company.

5.1 Innovation project in large consumer durables organization

We present a case of an innovation project in consumer durables manufacturing organization to enhance the perceived quality of no-frost refrigerator. The project follows a toll-gated product design process. This project is undertaken to increase the humidity levels in the crisper drawer at any surrounding temperature of refrigerator. The lower temperature impact the freshness of the vegetables of the refrigerator since the relative humidity is between 30-45%. The innovative component controls the relative humidity between 70-85% in the crisper cabinet of a no frost refrigerator. Thus, the innovation project helped in providing cost effective method with least manual intervention for freshness of vegetables. The project network and the precedence relationships with inputs and outputs of various activities is shown in Figure 3 and Table IV respectively. Here, we consider a two-stage project, i.e. the project level and work packages level. The safety audit is conducted to find the RPN of each activity. In order to compute the yield for the project, we begin from the work package and subsequently compute the RTY at the project level. Table V and Table VI shows the FPY computations for each of the activities at each level for quality, cost, time, safety and environment sustainability for project and work packages respectively. Later we compute RTY values for work packages and project respectively. Due to confidentiality, we show the input and output values only at the work package level. However, the yield provides information about the criticality of each work package. RTY and SL calculated for each work package using expression 4 and is shown in Table VII.

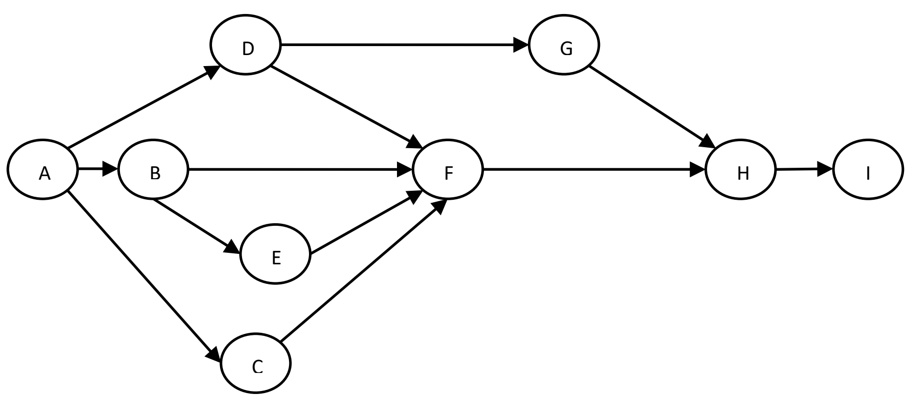

Figure 3. Activity-on-node representation of innovation project

Table IV. Target and estimated values of various criteria for each activity

Activity	Description	Pred.	TO	TI	BC	AC	ET	TT	RPN	RR	SAQ	OAQ	SNL	ONL	WU	WG
A	Model Lab Testing	-	98	100	800	765	30	26	150	0	50	54	75	82	160	160
B	Piezo Assembly	A	95	98	400	450	30	32	240	1	50	42	75	56	78	85
C	Water Tank Assembly	A	95	95	200	140	10	10	140	2	50	42	75	75	85	85
D	Harness Assembly	A	94	95	300	310	45	40	176	1	50	51	75	63	119	130
E	Wick Assembly	B	94	94	200	180	10	10	41	0	50	45	75	56	90	90
F	Docking Assembly	B,C,D,E	93	94	200	200	30	28	239	0	50	42	75	65	80	80
G	UI Housing Assembly	D	93	93	300	275	30	25	79	1	50	45	75	65	105	110
H	Prototype Testing	F,G	91	93	1100	1020	45	47	120	1	50	47	75	81	130	140
I	Field Testing	H	90	91	1500	1560	30	30	150	1	50	51	75	72	78	80

Pred.: Predecessor

Table V. FPY values for project activities

Activity	Description	Pred.	FPY quality	FPY cost	FPY Time	FPY safety	FPY env.
A	Model Lab Testing	-	0.98	1	1	1	0.947
B	Piezo Assembly	A	0.969	0.89	0.937	0.889	0.972
C	Water Tank Assembly	A	1	1	1	0.870	1
D	Harness Assembly	A	0.989	0.967	1	0.919	0.993
E	Wick Assembly	B	1	1	1	1	1
F	Docking Assembly	B,C,D,E	0.989	1	1	1	1
G	UI Housing Assembly	D	1	1	1	0.963	0.985
H	Prototype Testing	F,G	0.978	1	0.957	0.944	0.951
I	Field Testing	H	0.989	0.961	1	0.931	0.985

Table VI. FPY values for work package

Activity	Description	Pred.	FPY quality	FPY cost	FPY Time	FPY safety	FPY env.
BA	Wick Holder	-	0.998	0.968	1.000	1.000	1.000
BB	Piezo compression seal	BA	0.997	1.000	1.000	0.996	0.987
BC	Piezo top seal	BB	0.997	1.000	1.000	0.996	1.000
BD	Piezo cell	BC	0.964	0.887	1.000	0.905	0.965
BE	Piezo Bottom seal	BD	0.997	1.000	1.000	0.996	1.000
CA	Poppet Valve seal	-	0.997	1.000	0.982	0.996	1.000

CB	Water Tank	CA	0.988	0.923	1.000	0.981	1.000
CC	Sealed O-ring	CB	0.996	1.000	0.975	0.996	0.990
CD	Water Tank cap	CC	0.997	1.000	1.000	0.994	1.000
CE	Poppet valve spring	CD	0.997	1.000	1.000	0.996	1.000
CF	Poppet plunger	CC,CD	0.995	1.000	1.000	1.000	1.000
DA	Main board	-	0.998	1.000	1.000	1.000	1.000
DB	Harness	DA	0.988	0.943	0.985	0.978	0.985
DC	Foam	DB	0.997	1.000	1.000	1.000	0.975
DD	Grommet	DC	0.999	1.000	1.000	1.000	1.000
DE	RC liner	DD	0.997	0.976	1.000	0.997	1.000
EA	Wick	-	0.996	1.000	1.000	1.000	1.000
EB	Wick plunger	EA	0.998	1.000	1.000	1.000	1.000
EC	Spring washer	EB	0.997	1.000	0.988	1.000	1.000
FA	Docking station	-	0.982	0.959	1.000	0.963	1.000
FB	Piezo housing	FA	0.997	1.000	1.000	1.000	1.000
FC	Male docking pin	FB	0.994	0.968	1.000	1.000	1.000
FD	Female docking pin	FC	0.993	0.980	1.000	1.000	1.000
GA	Humidity sensor	-	0.998	1.000	0.967	1.000	0.988
GB	UI cover	GA	0.999	1.000	1.000	0.997	1.000
GC	UI casing	GB	0.998	1.000	1.000	1.000	1.000
GD	Printed Circuit Board	GB	0.997	1.000	1.000	0.990	1.000

Legend: A word indicate an work package under that activity (example CA, CB, CC etc. i.e. CA is a work package under activity C)

Table VII. RTY and SL for criteria for the work packages

Work Package	Quality		Cost		Time		Safety		Environment	
	RTY	SL	RTY	SL	RTY	SL	RTY	SL	RTY	SL
A	0.98	2.75	1	6	1	6	1	6	0.947	2.65
B	0.953	3.2	0.859	2.55	1	6	0.895	2.75	0.953	3.2
C	0.973	3.45	0.923	2.95	0.955	3.2	0.969	3.35	0.99	3.85
D	0.979	3.5	0.921	2.95	0.985	3.7	0.976	3.5	0.961	3.25
E	0.991	3.9	1	6	0.988	3.8	1	6	1	6
F	0.996	4.15	0.910	2.85	1	6	0.963	3.3	1	6
G	0.994	4	1	6	0.967	3.35	0.992	3.9	1	6
H	0.978	3.5	1	6	0.957	3.2	0.944	3.1	0.951	3.15
I	0.989	3.8	0.961	3.3	1	6	0.931	3	0.985	3.7

Next, we compute the RTYs for quality, cost, time, safety, and environment sustainability and find the overall RTY and SL for the innovation project as shown in Table VIII. SL for quality, cost, time, safety, and environment sustainability are 2.75, 2.25, 2.9, 2.05 and 2.65 respectively.

$$RTY_{Project} = A*\{1/3*(D*(1/2*G*H*I+1/2*F*H*I) + 1/3*B*(1/2*F*H*I+1/2*E*F*H*I) + 1/3*C*F*H*I\}$$

$RTY_{Project\_quality}$ = 0.98*{1/3*(0.968*(1/2*0.994*0.978*0.989 + 1/2*0.985*0.976*0.989) + 1/3*0.924*(1/2*0.985*0.978*0.989+1/2*0.991*0.989*0.978*0.989) + 1/3*0.973*0.985*0.978*0.989} = 0.8917

$RTY_{project\_time}$ = 0.9108; $RTY_{project\_safety}$ = 0.7143; $RTY_{project\_environment}$ = 0.8745

Table VIII. RTY for project activities

Component	Quality		Cost		Time		Safety		Environment	
	RTY	SL	RTY	SL	RTY	SL	RTY	SL	RTY	SL
Project	0.8917	2.75	0.7644	2.25	0.9108	2.9	0.7143	2.05	0.8745	2.65
A	0.9800	3.6	1.0000	6	1.0000	6	1.0000	6	0.947	3.1
B	0.9235	2.95	0.7645	2.25	0.9370	3.05	0.7957	2.35	0.972	3.4
C	0.9730	3.4	0.9230	2.95	0.9550	3.2	0.8430	2.5	1	6
D	0.9682	3.35	0.8906	2.75	0.9850	3.7	0.8969	2.75	0.993	4
E	0.9910	3.9	1.0000	6	0.9880	3.8	1.0000	6	1	6
F	0.9850	3.7	0.9100	2.85	1.0000	6	0.9630	3.3	1	6
G	0.9940	4	1.0000	6	0.9670	3.35	0.9553	3.2	0.985	3.7
H	0.9780	3.5	1.0000	6	0.9570	3.2	0.9440	3.1	0.951	3.15
I	0.9890	3.8	0.9610	3.3	1.0000	6	0.9310	3	0.985	3.7

Group AHP is applied to find the weights for each criteria. Group AHP using geometric mean approach is effective in checking consistency of DMs judgements, and preserve reciprocal property [43-44]. The obtained results are as shown in Table IX. SL for the project is computed by using expressions 9 and 10 and DPMO sigma conversion table.

Table IX. Weight Evaluations (Case 1)

		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Group
Weights	Quality	0.210	0.245	0.301	0.297	0.351	0.285
	Cost	0.134	0.075	0.086	0.079	0.094	0.092
	Time	0.418	0.437	0.342	0.315	0.237	0.344
	Safety	0.118	0.101	0.135	0.124	0.135	0.124
	Environment	0.119	0.142	0.136	0.185	0.184	0.155
Consistency Check	λ max	5.207	5.378	5.250	5.424	5.240	5.066
	CI	0.052	0.094	0.062	0.106	0.060	0.017
	CR	0.046	0.084	0.056	0.095	0.054	0.015

$RTY_{project}$ = 0.8619

$DPMO_p = (1 - RTY_{project})*10^6$ = 138071; Overall Sigma Level SL_p = 2.55

The project has an overall SL of 2.55. However, while the project was being conducted, the budget for the project was revised, as the capital expenditure for a major project of the organization running in parallel was higher than expected. Hence, we see that the final SL for cost criteria was lower than expected. Secondly, due to strict safety restrictions followed by the organization, the SL for safety is also low. Thus, to improve project performance, it is important to provide a range of targeted values so that during the implementation phase, necessary actions can be taken without compromising on the SL for the project.

5.2 Construction of a railway line for a mining company

Next, we present case of construction of a railway line in a mining organization. This railway line is designed for an automatic train control and dedicated tracks. The need to develop this construction was due to the increase in the workload for transportation of goods and the aging factor of the existing tracks. For illustration, we consider only a subset of the entire project because of the limitation of space constraint, and to avoid un-necessary repetitions of similar procedure. The data provided in this manuscript is suitably modified to prevent loss of competitive information and ease of understanding.

Here, we consider a three-stage project, i.e. the project is decomposed to components and components are further decomposed to work packages.

5.2.1 Project network through precedence relationships

The precedence diagram and its' activities are shown in Figure 4 and Table X.

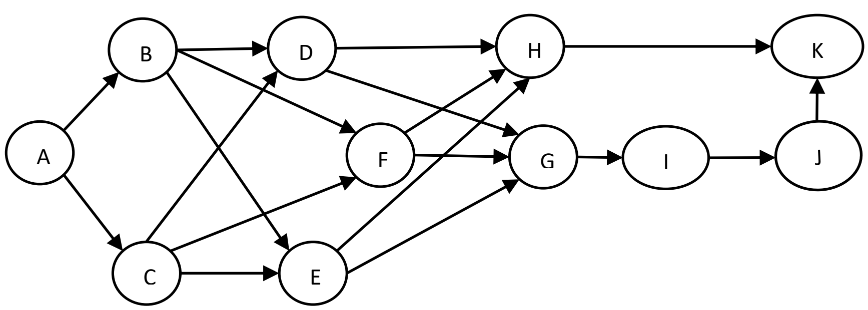

Figure 4. Activity-on-node representation of the railway construction project

Table X. Precedence relationship for activities of railway project

Activity	Description	Predecessors
A	Site clearing and removal of trees	---
B	General excavation	A
C	Grading general area	A

D	Embankment and cut structure	B,C
E	Placing formwork and reinforcement for concrete	B,C
F	Bridges/Viaducts ad tunnels	B,C
G	Track Layout	D,E,F
H	Rolling stock	D,E,F
I	Electrification	G
J	Signalling and communications	I
K	Buildings including stations	H,J

The flow of network activities of the Track Layout (G) is shown in Table XI. Further, we identify activity GE (Manufacture of Track Slabs) as the work package. This activity GE is carved out of activity G (Track Layout). The flow of network activities for manufacture of track slabs is shown in Table XII.

Table XI. Precedence relationship for activities of Track Layout (Activity G)

Activity	**Description**	**Predecessors**
GA	Installation of track construction work base/ maintenance depot	---
GB	Fabrication of mainline turnout/temporary turnout	---
GC	Transport of rails (by sea/on land)	---
GD	Setting of datum point	---
GE	Manufacture/transport of track slabs	---
GF	Transport of rails (by existing railways)	GC
GG	Laying of temporary track for construction work	GA,GB,GF
GH	Receiving and transporting of track slabs	GD,GE,GG
GI	Laying of track slabs	GH
GJ	CA mortar grouting	GI
GK	Secondary welding	GJ
GL	Rail top straightening	GK
GM	Long-rail axial force resetting/Tertiary welding	GL
GN	Rail top grinding	GM

Table XII. Precedence relationship for Manufacture of track slab (activity GE)

Activity	**Description**	**Predecessors**
GEA	Reinforcing bar processing/fabrication	---
GEB	Ready mixed concrete kneading	---
GEC	Fabrication of bolted parts	---
GED	Setting reinforcing bar cage	GEA, GEB
GEE	Fixing accessories	GED

GEF	Concrete casting	GEE
GEG	Primary curing	GEF
GEH	Frame removal	GEG
GEI	Rollover/finishing	GEH
GEJ	Secondary curing	GEI
GEK	Storage	GEJ, GEC
GEL	Fixing tie plates	GEK
GEM	Shipping	GEL

In order to compute the yield for the project, we begin from the lowermost level of the project i.e. work package and subsequently compute the RTY of component level and later at the project level. First, we find the FPY for the activities in the work package. Table XV shows the FPY computations for each of the activities at each level for quality, cost, time, safety and environment sustainability for work package. Later we compute RTY values using the expressions discussed earlier. These values are also shown in the Table XV.

We calculate the RTY for this package, considering a uniform weight of 0.5 for all parallel activities. The sample calculation is shown as follows, here, for instance, p_{GEA} indicates the FPY for GEA activity:

$RTY_{work\ package\ (GE\_quality)} = (w_{11} \times p_{GEA} + w_{12} \times p_{GEB}) \times (w_{21} \times p_{GEC} + w_{22} \times p_{GEJ}) \times p_{GED} \times p_{GEE} \times p_{GEF} \times p_{GEG} \times p_{GEH} \times p_{GEI} \times p_{GEK} \times p_{GEL} \times p_{GEM}$

$RTY_{GE\_quality}$ = (0.5×999/1000+0.5×999/999) × (0.5×999/999+0.5×995/995) × 998/999 × 998/999 × 997/998 × 996/998 × 995/997 × 994/996 × 993/95 × 995/995 × 993/995 = 0.987

$Sigma\ level_{GE\_quality}$ = 3.70

Table XIII. FPY and RTY for work package

Activity	**GEA**	**GEB**	**GEC**	**GED**	**GEE**	**GEF**	**GEG**	**GEH**	**GEI**	**GEJ**	**GEK**	**GEL**	**GEM**
AI	1000	999	999	999	999	998	998	997	996	995	995	995	995
RJ	1	0	0	0	1	0	1	1	1	0	0	0	2
RW	0	0	0	1	0	1	1	1	1	0	2	0	0
$FPY_{Quality}$	999/1000	1	1	998/999	998/999	997/998	498/499	995/997	497/498	1	993/995	1	993/995
BC	23000	57500	122000	83000	26500	17500	27000	10500	24000	79500	46500	12700	130000
MC	22077	57610	122141	82985	26330	17391	26847	10330	23932	79387	46483	12641	130894
RJC	63	0	0	0	72	56	74	41	70	0	0	0	67
RWC	0	0	0	245	0	157	594	34	77	224	625	0	0
AC	22140	57610	122141	83229	26402	17604	27515	10405	24079	79611	47107	12641	130961
FPY_{Cost}	1	523/524	865/866	725/727	1	673/677	367/374	1	304/305	716/717	383/388	1	947/954
ET	3	5	2	6	5	3	4	3	4	2	2	4	6
AT	2.7	4.5	1.8	5.4	4.5	3.02	4.05	2.9	4.05	1.8	2	3.6	5.6
WT	0.02	0.11	0	0.03	0.03	0.07	0	0.04	0.05	0.01	0.04	0.13	0.09
TT	2.72	4.61	1.8	5.43	4.53	3.09	4.05	2.94	4.1	1.81	2.04	3.73	5.69
FPY_{Time}	1	1	1	1	1	100/103	80/81	1	40/41	1	50/51	1	1
HC	0.204	0.286	0.108	0.207	0.095	0.308	0.101	0.209	0.018	0.068	0.025	0.233	0.085
I	1	2	2	3	1	3	4	1	1	5	1	2	1
F	1	3	4	5	4	2	1	1	2	1	1	2	2
RR	2	0	1	1	1	0	1	3	1	1	0	0	0
RPN	0.204	1.716	0.864	3.105	0.38	1.848	0.404	0.209	0.036	0.34	0.025	0.932	0.17
ARR	0.010	0	0.021	0.077	0.009	0	0.010	0.016	0.001	0.008	0	0	0
FPY_{Safety}	98/99	1	320/327	12/13	947/956	1	99/100	507/515	1	824/831	1	1	1
SAQ	50	50	50	50	50	50	50	50	50	50	50	50	50
SNL	75	75	75	75	75	75	75	75	75	75	75	75	75
OAQ	41.1	50.8	51.1	38.7	43.2	51.3	43.4	35.2	42	49.7	53.2	50.4	33.3
ONL	65.4	60.6	59.2	76.6	65.1	69.9	75.2	78	72.7	72.4	77.5	58.9	65.3
%WU	98	99.2	99	99.46	97.3	97.32	99.1	99.65	98.4	98.34	99.18	97.89	99.67
$FPY_{Airquality}$	1	125/127	500/511	1	1	500/513	1	1	1	1	125/133	125/126	1
FPY_{Noise}	1	1	1	375/383	1	1	375/376	25/26	1	1	30/31	1	1
FPY_{Waste}	49/50	124/125	99/100	921/926	937/963	581/597	881/889	854/857	123/125	237/241	121/122	232/237	302/303
$FPY_{Environment}$	138/139	559/564	755/764	673/678	815/823	407/415	760/763	439/444	863/868	499/502	932/965	373/377	841/842

$RTY_{GE\_quality} = 0.99$, $SL_{GE\_quality} = 3.70$, $RTY_{GE\_cost} = 0.95$, $SL_{GE\_cost} = 3.15$, $RTY_{GE\_time} = 0.92$, $SL_{GE\_time} = 2.90$, $RTY_{GE\_safety} = 0.87$, $SL_{GE\_safety} = 2.65$, $RTY_{GE\_environment} = 0.89$, $SL_{GE\_environment} = 2.75$

AI: Actual input, RJ: Number of reject, RW: Number of rework, BC: Budgeted cost, MC: Manufacturing cost, RJC: Reject cost, RWC: Rework cost, AC: Actual cost, ET: Expected time, AT: Actual time, WT: Waiting time, TT: Total time, HC: Hazard criticality, I: Impact, F: Frequency, RR: Risk rating, RPN: Risk priority number, ARR: Adjusted risk rating, SAQ: Standard air quality, SNL: Standard noise level, OAQ: Observed air quality, ONL: Observed noise level, %WU: Percent waste utilised, FPY_x: First pass yield for x criterion

On the similar basis, we compute the RTYs for cost, time, safety, and environment sustainability and find the overall RTY for manufacture of track slabs.

$RTY_{GE\_cost} = 0.95$, $SL_{GE\_cost} = 3.15$, $RTY_{GE\_time} = 0.92$, $SL_{GE\_time} = 2.90$, $RTY_{GE\_safety} = 0.87$, $SL_{GE\_safety} = 2.65$, $RTY_{GE\_air\ quality} = 0.89$, $RTY_{GE\_noise} = 0.91$, $RTY_{GE\_waste} = 0.86$, $RTY_{GE\_environment} = 0.89$, $SL_{GE\_environment} = 2.75$

Similarly, we compute RTYs of all the other work packages and they are as shown in Table XIV.

Table XIV. RTY for work packages of particular component.

Activity	**$RTY_{quality}$**	**RTY_{cost}**	**RTY_{time}**	**RTY_{safety}**	**$RTY_{environment}$**
GA	0.96	0.93	0.99	0.97	0.99
GB	0.92	0.94	0.96	0.99	0.94
GC	0.98	1	0.99	1	0.98
GD	1	1	0.92	1	0.99
GE	0.99	0.95	0.98	0.87	0.89
GF	0.98	0.99	0.97	0.96	0.96
GG	1	1	0.99	0.97	1
GH	0.96	0.96	1	0.99	1
GI	0.98	1	0.99	0.99	0.92
GJ	1	0.97	0.95	0.98	1
GK	0.99	0.98	0.98	1	0.99
GL	0.97	1	0.95	0.97	0.99
GM	0.98	0.97	0.98	0.99	0.97
GN	0.99	1	1	1	1

5.2.2 Component Level

Next, we find the RTYs for the activities at component level. Here, we show the computations for a component level activity, i.e. laying of slab tracks. The computation of FPY of component for quality, cost, time, safety and environment sustainability is as shown in Table XV. Here, we assume equal weights to the parallel activities.

Table XV. FPY and RTY for component

Activity	**GA**	**GB**	**GC**	**GD**	**GE**	**GF**	**GG**	**GH**	**GI**	**GJ**	**GK**	**GL**	**GM**	**GN**
AI	1000	1000	1000	999	999	999	998	998	997	997	996	996	994	994
RJ	0	0	1	0	0	1	0	1	0	1	0	2	0	0
RW	1	1	0	2	2	1	1	0	2	0	1	0	2	1
FPYq(p)	999/1000	999/1000	999/1000	997/999	997/999	997/999	997/998	997/998	995/997	996/997	995/996	497/498	496/497	993/994
$RTY_{wp\_quality}$	0.96	0.92	0.98	1	0.99	0.98	1	0.96	0.98	1	0.99	0.97	0.98	0.99
$FPY_{quality}$	0.96	0.92	0.98	1.00	0.99	0.98	1.00	0.96	0.98	1.00	0.99	0.97	0.98	0.99
BC	176500	1307000	450000	30000	685000	170000	350000	570000	923000	486000	97000	223146	93000	335000
MC	176436	1307024	447099	30377	697762	169020	341433	567453	923469	477139	97043	223446	92397	331135
RJC	549.9	0	413.7	0	491	570.2	0	0	0	0	0	686.9	815	927.5
RWC	2134.4	91030	105	0	496.6	476	10786.4	6962.3	2543.3	12515.5	0	2169.3	385	0
AC	179120	1398054	447618	30377	698750	170066	352219	574415	926012	489655	97043	226302	93597	332063
FPYc(p)	741/752	689/737	1	557/564	548/559	1	631/635	129/130	613/615	133/134	1	707/717	779/784	1
RTY_{wp_cost}	0.93	0.94	1	1	0.95	0.99	1	0.96	1	0.97	0.98	1	0.97	1
FPY_{cost}	0.9164	0.8788	1	0.9876	0.9313	0.9896	0.9937	0.9526	0.9967	0.9628	0.9796	0.9861	0.9638	1
ET	61	40	70	40	56	52	64	38	23	56	71	97	41	34
AT	62	39	68	41	52.3	46.8	57.6	36.8	22.8	50.4	68.1	96.7	40.1	33.4
WT	0.11	2.03	2.28	0.8	0	0	0.62	1.15	0.46	0.53	3.02	3.17	0.91	1.14
TT	62.11	41.03	70.28	41.8	52.3	46.8	58.22	37.95	23.26	50.93	71.12	99.87	41.01	34.54
FPYt(p)	55/56	233/239	250/251	200/209	1	1	1	1	973/984	1	592/593	169/174	1	63/64
RTY_{wp_time}	0.99	0.96	0.99	0.92	0.98	0.97	0.99	1	0.99	0.95	0.98	0.95	0.98	1
FPY_{time}	0.97	0.94	0.99	0.88	0.98	0.97	0.99	1.00	0.98	0.95	0.98	0.92	0.98	0.98
HC	0.183	0.135	0.673	0.005	0.27	0.115	0.377	0.272	0.713	0.523	0.88	0.45	0.203	0.177
I	1	3	2	2	3	3	2	4	1	3	2	2	4	2
F	3	2	1	1	2	2	3	2	2	5	1	2	2	3

RR	2	0	1	2	1	0	1	1	1	0	1	0	0	2
RPM	0.55	0.81	1.35	0.01	1.62	0.69	2.26	2.18	1.43	7.85	1.76	1.80	1.62	1.06
ARR	0.0100	0	0.0123	0	0.0148	0	0.0206	0.0198	0	0.0000	0.0160	0	0	0.0193
FPYs(p)	0.99	1	0.99	1	0.99	1	0.98	0.98	1	1.00	0.98	1.00	1.00	0.98
RTY_{wp_safety}	0.97	0.99	1	1	0.87	0.96	0.97	0.99	0.99	0.98	1	0.97	0.99	1
FPY_{safety}	0.96	0.99	0.99	1.00	0.86	0.96	0.95	0.97	0.98	0.98	0.98	0.97	0.99	0.98
SAQ	50	50	50	50	50	50	50	50	50	50	50	50	50	50
SNL	75	75	75	75	75	75	75	75	75	75	75	75	75	75
OAQ	49	50.7	44.6	49	48.4	53	54.6	51.3	50.4	50.3	51.2	52.2	43.6	48.3
ONL	48	70.8	67.8	65	75	74	41.6	73.2	75.9	74.1	73.7	58.3	80.1	69.4
%WU	99.2	99.5	98.4	99.8	99.5	98	98.1	99.7	98.2	97.6	99.25	99.3	99.6	99.67
FPYaq(p)	1	500/507	1	1	1	50/53	250/273	500/513	125/126	500/503	125/128	250/261	1	1
FPYn(p)	1	1	1	1	1	1	1	1	250/253	1	1	1	250/267	1
FPYw(p)	124/125	199/200	123/125	499/500	199/200	49/50	568/579	332/333	491/500	122/125	397/400	142/143	249/250	302/303
FPYe(p)	346/347	141/142	863/868	1	555/556	203/209	470/489	739/747	157/159	272/275	511/517	53/54	382/389	841/842
$RTY_{wp\_environment}$	0.99	0.94	0.98	0.99	0.89	0.96	1	1	0.92	1	0.99	0.99	0.97	1
$FPY_{environment}$	0.99	0.93	0.97	0.99	0.89	0.93	0.96	0.99	0.91	0.99	0.98	0.97	0.95	1.00

$RTY_{G\_quality} = 0.84$, $SL_{G\_quality} = 2.50$, $RTY_{G\_cost} = 0.80$, $SL_{G\_cost} = 2.35$, $RTY_{G\_time} = 0.76$, $SL_{G\_time} = 2.22$, $RTY_{safety} = 0.79$, $SL_{G\_safety} = 2.32$, $RTY_{G\_environment} = 0.74$, $SL_{G\_environment} = 2.15$

AI: Actual input, RJ: Number of reject, RW: Number of rework, BC: Budgeted cost, MC: Manufacturing cost, RJC: Reject cost, RWC: Rework cost, AC: Actual cost, ET: Expected time, AT: Actual time, WT: Waiting time, TT: Total time, HC: Hazard criticality, I: Impact, F: Frequency, RR: Risk rating, RPN: Risk priority number, ARR: Adjusted risk rating, SAQ: Standard air quality, SNL: Standard noise level, OAQ: Observed air quality, ONL: Observed noise level, %WU: Percent waste utilised, FPYx(p): Intermediate First pass yield of x criterion, RTYwp_x: Rolled throughput yield of x criterion for work package, FPYx: First pass yield of x criterion

We compute the RTYs for quality, cost, time, safety, and environment sustainability and find the overall RTY for laying of slab tracks.

$RTY_{G\_quality}$ = 0.84, $SL_{G\_quality}$ = 2.50, RTY_{G_cost} = 0.80, SL_{G_cost} = 2.35, RTY_{G_time} = 0.76, SL_{G_time} = 2.22, RTY_{G_safety} = 0.79, SL_{G_safety} = 2.32, $RTY_{G\_environment}$ = 0.74, $SL_{G\_environment}$ = 2.15

We calculate the RTY of all the components and is shown in Table XVI.

Table XVI. RTY for components of the project

Activity	Description	$RTY_{quality}$	RTY_{cost}	RTY_{time}	RTY_{safety}	$RTY_{env.}$
A	Site clearing and removal of trees	0.99	0.98	0.98	0.99	0.88
B	General excavation	0.96	0.99	0.99	0.96	0.97
C	Grading general area	0.97	0.95	0.94	0.97	0.92
D	Embankment and cut structure	0.92	0.98	0.87	0.86	0.93
E	Placing formwork and reinforcement for concrete	0.97	0.97	0.91	0.9	0.97
F	Bridges/Viaducts and tunnels	0.88	0.89	0.95	0.88	0.96
G	Track Layout	0.84	0.8	0.76	0.79	0.74
H	Rolling stock	0.96	0.96	0.96	0.93	0.89
I	Electrification	0.95	0.96	0.96	0.96	0.98
J	Signalling and communications	0.97	0.94	0.93	0.99	0.95
K	Buildings including stations	0.98	0.99	0.99	0.97	0.99

5.2.3 Project Level

We consider the RTY of the component level to generate RTY of project. We assume equal weights for activities in parallel. Hence, Activity B and C will have equal weight (0.5) and D, E and F have equal weight (0.5). The computations of RTY for the project considering all the criteria is as shown in Table XVII.

Table XVII. FPY calculation for project

Activity	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
AI	1000	999	999	999	996	994	993	990	990	987	987
RJ	1	0	0	3	2	1	3	0	3	0	0
RW	2	1	2	1	1	0	0	2	1	1	0
FPYq(p)	332/333	998/999	997/999	995/999	331/332	993/994	330/331	494/495	493/495	986/987	1
RTYc_quality	0.99	0.96	0.97	0.92	0.97	0.88	0.84	0.96	0.99	0.97	0.98
FPYquality	0.99	0.96	0.97	0.92	0.97	0.88	0.84	0.96	0.99	0.97	0.98
BC	325000	395000	989000	5500000	2560000	2270000	4400000	7200000	2270000	1650000	1300000
MC	304184	364810	909360	5423774	2549271	2267215	4287001	7388261	2257618	1592125	1286503
RJC	7864	0	0	0	7044	6581	0	6818	6778	5533	4883
RWC	9007	38072	85529	124956	7045	27737	25826	10545	0	46315	13176
AC	321055	402882	994889.4	5548730	2563360	2301533	4312827	7405623	2264396	1643972	1304562
FPYc(p)	1	451/460	168/169	903/911	762/763	72/73	1	35/36	1	1	285/286
RTYc_cost	0.98	0.99	0.95	0.98	0.97	0.89	0.8	0.96	0.96	0.94	0.99
FPYcost	0.98	0.97	0.94	0.97	0.97	0.88	0.80	0.93	0.96	0.94	0.99
ET	137	128	574	485	490	752	775	550	520	304	297
AT	114.3	113.6	488.8	388.8	408	682.4	697.5	410.4	422.4	294.8	222.3
WT	29.45	16.06	42.5	102.54	57.33	27.63	19.38	98.9	98.31	15.98	77.71
TT	143.75	129.66	531.3	491.34	465.33	710.03	716.88	509.3	520.71	310.78	300.01
FPYt(p)	548/575	694/703	1	153/155	1	1	1	1	732/733	269/275	296/299
RTYc_time	0.98	0.99	0.94	0.87	0.91	0.95	0.76	0.96	0.96	0.93	0.99
FPYtime	0.93	0.98	0.94	0.86	0.91	0.95	0.76	0.96	0.96	0.91	0.98
HC	0.429	0.648	0.813	0.299	0.109	0.39	0.586	0.108	0.021	0.333	0.452
I	1	1	4	4	4	4	1	2	2	4	3
F	2	2	3	3	0	1	2	1	3	1	4

RR	2	0	0	1	0	2	4	0	3	3	2
RPM	0.86	1.3	9.75	3.59	0	1.56	1.17	0.22	0.13	1.33	5.43
ARR	0.006	0	0	0.013	0	0.011	0.017	0	0.001	0.014	0.039
FPYs(p)	0.994	1	1	0.987	1	0.989	0.983	1	0.999	0.986	0.961
RTYc_safety	0.99	0.96	0.97	0.86	0.9	0.88	0.79	0.93	0.96	0.99	0.97
FPYsafety	0.98	0.96	0.97	0.85	0.90	0.87	0.78	0.93	0.96	0.98	0.93
SAQ	50	50	50	50	50	50	50	50	50	50	50
SNL	75	75	75	75	75	75	75	75	75	75	75
OAQ	49.45	50.85	49.63	48.14	58.68	50.1	50.54	55	48.59	40.47	49.87
ONL	74.13	74.17	74.03	72.44	59.56	77.68	67.54	77.09	71.86	78.15	73.12
%WU	98.9	99.65	99.73	99.43	99.07	99.36	99.04	99.99	97.95	99.55	99.14
FPYaq(p)	1	647/658	1	1	553/649	500/501	463/468	10/11	1	1	1
FPYn(p)	1	1	1	1	1	28/29	1	933/959	1	500/521	1
FPYw(p)	90/91	854/857	739/741	349/351	213/215	621/625	619/625	1	430/439	885/889	807/814
FPYe(p)	503/505	391/394	1	486/487	679/722	739/748	132/133	23/24	269/271	245/248	322/323
RTYc_environment	0.88	0.97	0.92	0.93	0.97	0.96	0.74	0.89	0.98	0.95	0.99
FPYenvironment	0.88	0.96	0.92	0.93	0.91	0.95	0.73	0.85	0.97	0.94	0.99

$RTY_{project\_quality}$ = 0.76, $SL_{project\_quality}$ = 2.22, $RTY_{project\_cost}$ = 0.73, $SL_{project\_cost}$ = 2.12, $RTY_{project\_time}$ = 0.65, $SL_{project\_time}$ = 1.85, $RTY_{project\_safety}$ = 0.67, $SL_{project\_safety}$ = 1.95, $RTY_{project\_environment}$ = 0.58, $SL_{project\_environment}$ = 1.70

AI: Actual input, RJ: Number of reject, RW: Number of rework, BC: Budgeted cost, MC: Manufacturing cost, RJC: Reject cost, RWC: Rework cost, AC: Actual cost, ET: Expected time, AT: Actual time, WT: Waiting time, TT: Total time, HC: Hazard criticality, I: Impact, F: Frequency, RR: Risk rating, RPN: Risk priority number, ARR: Adjusted risk rating, SAQ: Standard air quality, SNL: Standard noise level, OAQ: Observed air quality, ONL: Observed noise level, %WU: Percent waste utilised, FPYx(p): Intermediate First pass yield of x criterion, RTYc_x: Rolled throughput yield of x criterion for component, FPYx: First pass yield of x criterion

We compute the RTYs for quality, cost, time, safety, and environment sustainability and find the overall RTY for the project.

$RTY_{project\_quality}$ = 0.76, $RTY_{project\_cost}$ = 0.73, $RTY_{project\_time}$ = 0.65, $RTY_{project\_safety}$ = 0.67, $RTY_{project\_environment}$ = 0.58

On the similar basis, SL for quality, cost, time, safety, and environment sustainability are 2.22, 2.12, 1.85, 1.95 and 1.70 respectively.

Preference weights for Quality, Cost, Time, Safety and Environment sustainability were obtained as 0.194, 0.158, 0.087, 0.411 and 0.150 respectively with a consistency ratio of 0.009 using Group AHP [43-45] (Table XVIII). Similarly, the weights for the sub-criteria of environment sustainability, which were air pollution, noise level and waste were obtained as 0.3804, 0.2602 and 0.3594 respectively. Finally, SL for the project is computed by using expressions 9 and 10 and DPMO sigma conversion table.

Table XVIII. Weight Evaluations (Case 2)

		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Group
Weights	Quality	0.149	0.207	0.152	0.258	0.174	0.194
	Cost	0.160	0.160	0.202	0.086	0.169	0.158
	Time	0.049	0.054	0.076	0.073	0.268	0.087
	Safety	0.493	0.434	0.441	0.292	0.312	0.411
	Environment	0.149	0.146	0.129	0.292	0.076	0.150
Consistency Check	λ max	5.325	5.275	5.248	5.058	5.278	5.0438
	CI	0.0813	0.068	0.062	0.014	0.069	0.01
	CR	0.072	0.061	0.055	0.013	0.0622	0.009

$RTY_{project}$ = 0.6816, $DPMO_p$ = (1-$RTY_{project}$)*10^6 = 318339

Overall Sigma Level SL_p = 1.95

6. Managerial Implications for applications

Here, we present some of the important findings based on the discussions so far. We presented a methodology using generalized formulae of RTY for project networks, and illustrated its application in an innovation and a construction project. In today's competitive context, project managers need to recognize the potential benefits of overall performance measurement of projects as compared to yield measurement of individual process. Managers who focus on yield improvement of entire project should realign the requirements of components, sub-components and work packages with the requirements of the project.

The proposed approach can be applied to any project to understand the impact of defects through RTY. The RTY is computed based on the FPY, which indicates the ‘first time’ good lot of a process. It thus indicates how good the process is, when executed for the first time. RTY has been applied to quality related metrics; this study enhances its applicability by evaluating new aspects of performance metrics like cost, time, safety and environment sustainability together. We also illustrate the performance evaluation of complex projects, once the entire project is decomposed into a series-parallel structure, and is constructed in a hierarchical way. The approach provides common standards to quantify the performance level of projects and help in achieving operational excellence. The integration of common methodology for measuring RTY for WBS can help in locating bottleneck process and provide learning for future/ongoing projects.

It is important to derive criteria weights to find the overall performance of the project. For example, Davies and Mackenzie [8] stated how the pace, planning and scheduling of London Olympics was dictated by an “immovable deadline”. As can be seen in the case discussed for innovation project in consumer durables organization, time is the major criteria (weight= 0.3440) since projects like these are deadline driven as the due dates are already known. Similarly, for the case of railway line construction, safety is the major criteria (weight = 0.4110). This can be attributed to the fact that safety related concerns are of most importance in construction projects. Secondly, quality of innovation and construction projects are always high in the priority list of the managers.

The effectiveness of SL in measuring processes’ performance has been well established in industry but still in the nascent stages when we compare supply chain networks and project networks. This paper answers the need for performance evaluations in projects using SL computation. The importance of SL computation at each level of WBS helps in finding the bottleneck operations. The overall SL in the case studies for the innovation project (2.55) and construction project (1.95) is driven by the complexity of the projects. The complexity in WBS will surely impact the overall SL of projects. Thus, we should focus on reducing complexity through coordination among stakeholders and system integration [8]. Even though higher SL is desired, criteria wise SL computation (2.22 for quality vs 1.70 for environment sustainability in construction project) provides information on where to focus for improving SL. Therefore, this research paper overcomes the limitation of computing only quality related SL in projects.

7. Conclusions and Future work

In this work, an attempt is made to compute the project performance through rolled throughput yield, given the WBS. The manager can eventually compute the RTY and hence SL of the entire project.

Thus, we address the three research questions discussed earlier. Firstly, our new model is the first major study to explore the performance of projects using RTY. The methodology enables computing SL at various stages/phases of the project, which can be considered as an additional output a manager can derive, apart from the usual rolled throughput computations. Secondly, the SL thus computed can be used for benchmarking with other process related projects as well. The manager can thus, easily pinpoint the area of improvement and develop a strategy with the help of the experts in the field for further improvement. Most importantly, this approach provides an opportunity to comprehend how good a process is, when executed for the first time. To the best of our knowledge, this approach is unique contribution in the area of managing projects, enabling the managers to get an overall project performance metric. Over a period of time, this methodology will also help the managers track the growth of improvements in the project, and provide a learning curve for future/ongoing projects. The viewpoints of stakeholders helps to bridge the gap between theory and practice regarding the relevance of criteria for projects. Finally, the integration of group AHP and RTY approach provides an aggregated score for throughput yield.

As an extension to this work, the methodology can be useful for multi-projects with WBS. The AON project network representation can integrate project level planning and scheduling for multiple projects running in parallel. Once we find the RTY for all the sub-processes, and sub-flows, the individual project performance can be synchronised with the strategic business goals for multi project organization. Thus, the operations schedule can be seamlessly linked to project schedule and program objectives. Further, we can validate the importance of conflicting criteria like time, cost, quality, safety and environment sustainability in the multi-project setting to resolve resource conflicts.

The implemented measure can be difficult to apply practically for novel projects where WBS is not clearly defined or the dependent criteria are not established priory. While ambiguity remains for the construction over-runs, quality defects, an upfront analysis of critical criteria can help mitigate project risks. Further, research needs to be undertaken to build uncertainty in target values of various activities in the model. Optimization and sensitivity analysis can be explored in such cases. Also, the knowledge of the industry and comparative data from other organizations can be useful to benchmark such projects.

Some limitations of the study are because of our assumption that opportunity at each activity is equal to one. However, the methodology can be suitably modified in order to accommodate more number of opportunities. The developed methodology for projects, considers all activities to be of finish to start type with lag equal to zero. Scope exists to develop further on this front too! Also, the project network is convertible to series and parallel arrangement. However, there may be some scenario where such an arrangement is not possible, here, we propose to apply the proposed approach through Graphical Evaluation and Review Technique (GERT). Development of methodology in such cases will be an extension to this work. On the positive note, this approach can be easily applied to a large-scale problem.

The proposed approach can be generalised for the projects of various kinds such as construction, information technology, manufacturing projects, customised projects, turnkey projects etc. We hope that this work will be of use to the researchers and practicing managers alike.

Acknowledgement

The authors thank the reviewers, editor, and the editor-in-chief for constructive suggestions, that has enabled to get the best of this work.

References

[1] X. Zu, L.D. Fredendall, and T.J. Douglas, "The evolving theory of quality management: The role of Six Sigma", *Journal of Operations Management*, vol. 26 no. 5, pp. 630–650, 2008.

[2] S.H. Han, M.J. Chae, M. J., Im, K. S., and Ryu, H. D., "Six sigma-based approach to improve performance in construction operations", *Journal of management in Engineering*, vol. 24 no. 1, pp. 21-31, 2008.

[3] K.T. Sullivan, "Quality Management Programs in the Construction Industry: Best Value Compared with Other Methodologies", *Journal of management in Engineering*, vol. 27 no. 4, pp. 210–219, 2011.

[4] H.J. Harrington, F. Voehl and W. Wiggin, "Applying TQM to the construction industry", *TQM Journal*, vol. 24 no. 4, pp. 352–362, 2012.

[5] V.R. Sreedharan, S. Rajasekar, S. Kannan Santhosh, P. Arunprasad and R. Trehan, "Defect

reduction in an electrical parts manufacturer: a case study", *TQM Journal*, vol. 30 no. 6, pp. 650–678, 2018.

[6] L. Clifford, "Why you can safely ignore Six Sigma." Fortune January, 140, 2001.

[7] S.B. Graves, "Six Sigma Rolled Throughput Yield", *Quality Engineering*, vol. 14 no. 2, pp. 257–266, 2002.

[8] A. Davies and I. Mackenzie, "Project complexity and systems integration: Constructing the London 2012 Olympics and Paralympics Games", *International journal of project management*, vol. 32 no. 5, pp.773-790, 2014.

[9] J.I. Park, D.K. Lee and J.H. Byun, "A Six Sigma Application Case Study to Improve a Rolled Throughput Yield of an Automobile Steering Wheel Manufacturing Process", *Journal of the Korean Society for Quality Management*, vol. 33 no. 1, pp.32, 2005.

[10] Y.D. Hwang, "The practices of integrating manufacturing execution systems and Six Sigma methodology", *The International Journal of Advanced Manufacturing Technology*, vol. 31 no. 1-2, pp.145-154, 2006.

[11] T. Dasgupta, "Using the six-sigma metric to measure and improve the performance of a supply chain" *Total Quality Management and Business Excellence*, vol. 14 no. 5, pp. 355-366, 2010

[12] O. Taylan, A.O. Bafail, R.M. Abdulaal and M.R. Kabli, "Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies." *Applied Soft Computing*, vol. 17, pp.105-116, 2014.

[13] A. Saghaei, H. Najafi, A. Mighi, and Z. Mosanna, "Mathematical modelling to improve Rolled Throughput Yield in a supply chain", *Production Planning & Control*, vol. 25 no. 5, pp. 414–424, 2012a.

[14] A. Saghaei, H. Najafi, and R. Noorossana, "Enhanced Rolled Throughput Yield : A new six sigma-based performance measure", *International Journal of Production Economics*, vol. 140 no. 1, pp. 368–373, 2012b.

[15] M.E. Eissa, M. Seif and M. Fares, "Assessment of purified water quality in pharmaceutical facility using six sigma tools", *International Journal of Pharmaceutical Quality Assurance*, vol. 6 no. 2, pp.54-72, 2015.

[16] X. Zhao, C.Y. Hsu, P.C. Chang and L. Li, "A genetic algorithm for the multi-objective optimization of mixed-model assembly line based on the mental workload", *Engineering Applications of Artificial Intelligence*, vol. 47, pp.140-146, 2016.

[17] S. Koziołek and D. Derlukiewicz, “Method of assessing the quality of the design process of construction equipment with the use of DFSS (design for Six Sigma)”, *Automation in Construction*, vol. 22, pp.223-232, 2012.

[18] J. Ravichandran, "Cost-based process weights for DPMO and the overall performance of an organization", *The TQM Magazine*, vol. 19 no. 5, pp. 442–453, 2007.

[19] R. Ben Ruben, S. Vinodh and P. Asokan, “Implementation of Lean Six Sigma framework with environmental considerations in an Indian automotive component manufacturing firm: a case study”, *Production Planning & Control*, vol. 28 no. 15, pp. 1193-1211, 2017.

[20] O.S. Vaidya, “A six sigma based approach to evaluate the on time performance of Indian railways”, *International Journal of Quality & Reliability Management*, vol. 35 no. 10, pp. 2212-2226, 2018.

[21] J.K. Larsen, G.Q. Shen, S.M. Lindhard and T.D. Brunoe, “Factors affecting schedule delay, cost overrun, and quality level in public construction projects”, *Journal of Management in Engineering*, vol. 32 no. 1, pp. 04015032, 2015.

[22] J. Antony and R. Banuelas, “Key ingredients for the effective implementation of Six Sigma program”, *Measuring Business Excellence*, vol. 6 no. 4, pp. 20-27, 2002.

[23] S.B. Graves, “Statistical quality control of a multistep production process using total process yield”, *Quality Engineering*, vol. 11 no. 2, pp. 187–195, 1998.

[24] T. Pyzdek, “The Six Sigma Handbook - A Complete Guide for Green Belts, Black Belts, and Managers at All Levels”, New York, NY: McGraw-Hill, 2003.

[25] J. Ravichandran, “Six-Sigma Milestone : An Overall Sigma Level of an Organization”, *Total Quality Management*, vol. 17 no. 8, pp. 973-980, 2006.

[26] T. Williams, “A classified bibliography of recent research relating to project risk management.” *European journal of operational research*, vol. 85 no. 1, pp.18-38, 1995.

[27] M. Keil, A. Rai, J.C. Mann and G.P. Zhang, “Why software projects escalate: The importance of project management constructs.” *IEEE Transactions on Engineering Management*, vol. 50 no. 3, pp.251-261, 2003.

[28] A.J. Bailetti, J.R. Callahan and P. DiPietro, “A coordination structure approach to the management of projects.” *IEEE Transactions on Engineering Management*, vol. 41 no. 4, pp.394-403, 1994.

[29] V.D. Wiley, R.F. Deckro and J.A. Jackson Jr, “Optimization analysis for design and planning

of multi-project programs." *European Journal of Operational Research*, vol. 107 no. 2, pp.492-506, 1998.

[30] D. Li and M. Lu, "Automated generation of work breakdown structure and project network model for earthworks project planning: a flow network-based optimization approach." *Journal of construction engineering and management*, vol. 143 no. 1, pp.04016086, 2017.

[31] J. Liu and M. Lu, "Synchronized Optimization of Various Management-Function Schedules in a Multiproject Environment: Case Study of Planning Steel Girder Fabrication Projects in Bridge Construction." *Journal of Construction Engineering and Management*, vol. 146 no. 5, pp. 05020002, 2020.

[32] P.E. Love, L. Ika, H. Luo, Y. Zhou, B. Zhong and W. Fang, "Rework, Failures, and Unsafe Behavior: Moving Toward an Error Management Mindset in Construction." *IEEE Transactions on Engineering Management*, 2020, doi: 10.1109/TEM.2020.2982463.

[33] K. El-Rayes and A. Kandil, "Time-cost-quality trade-off analysis for highway construction", *Journal of construction Engineering and Management*, vol. 131 no. 4, pp. 477-486, 2005.

[34] M.O. Sanni-Anibire, A. S. Mahmoud, M.A. Hassanain, and B.A. Salami, "A risk assessment approach for enhancing construction safety performance", *Safety science*, vol. 121 pp. 15-29, 2020.

[35] A. Shokri, J. Antony, J.A. Garza-Reyes, and M. Upton, "Scoping review of the readiness for sustainable implementation of Lean Six Sigma projects in the manufacturing sector", *International Journal of Quality & Reliability Management*, 2021, doi: 10.1108/IJQRM-08-2020-0261.

[36] T.L. Saaty (1977), "A scaling method for priorities in hierarchical structures", *Journal of mathematical psychology*, vol. 15 no. 3, pp. 234-281, 1977.

[37] O.S. Vaidya and S. Kumar, "Analytic hierarchy process: An overview of applications." *European Journal of operational research*, vol. 169 no. 1, pp.1-29, 2006.

[38] T. L. Saaty, "Group decision making and the AHP," in The Analytic Hierarchy Process, B. L. Golden, E. A. Wasil, and P. T. Harker, Eds., Berlin, Germany: Springer, 1989, pp. 59–67.

[39] J. Yue, B. Chen and M.C. Wang, "Generating ranking groups in the analytical hierarchy process." *Journal of the Operational Research Society*, vol. 57 no. 2, pp.190-201, 2006.

[40] P. Amenta, A. Lucadamo and G. Marcarelli, “On the choice of weights for aggregating judgments in non-negotiable AHP group decision making.” *European Journal of Operational Research*, vol. 288 no. 1, pp.294-301, 2021.

[41] L.A. Vidal, F. Marle and J.C. Bocquet, “Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects.” *Expert systems with applications*, vol. 38 no. 5, pp.5388-5405, 2011.

[42] N. Munier and E. Hontoria, “Uses and Limitations of the AHP Method.” *Management for Professionals*, Springer Nature, Switzerland, 2021.

[43] A. Jain, J.D. Darbari, A. Kaul, U. Ramanathan and P.C. Jha, “Facility Selection Model for BOPS Service for an Omnichannel Retail Chain.” *IEEE Transactions on Engineering Management*, 2020.

[44] O.U. Akaa, A. Abu, M. Spearpoint and S. Giovinazzi, “A group-AHP decision analysis for the selection of applied fire protection to steel structures.” *Fire Safety Journal*, vol. 86, pp.95-105, 2016.

[45] M. Tavana and A. Hatami-Marbini, “A group AHP-TOPSIS framework for human spaceflight mission planning at NASA.” *Expert Systems with Applications*, vol. 38 no. 11, pp.13588-13603, 2011.