# QUALITY ASSURANCE IN MANAGING A CABLE ROUTE DATABASE

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## ABSTRACT

Errors in a cable route database could undermine the adequacy of fire protection for a nuclear power plant that is based on fire hazard assessment and fire probabilistic safety assessment. An earlier paper examined the potential for these latent errors to compromise safety and the risk goals for a station. It suggested three strategies for addressing the incremental risk. This paper focuses on quality assurance in developing the cable route database as a means of reducing the risk. A strategic and cost effective methodology is presented to reduce the incremental risk while continuously reducing the probability of cable routing errors over the lifetime of the plant.

## 1. INTRODUCTION

Fire safety in a nuclear power plant (NPP) directly affects the nuclear safety goal of protecting plant personnel, the public and the environment from undue radiological risk. In the event of an internal fire, the plant capability for shutting down the reactor and keeping it shutdown, removing decay heat, confining radioactive material and monitoring plant status must be preserved [1, 2, 3]. The adequacy of fire protection for an NPP is verified quantitatively with a deterministic fire hazard assessment (FHA). This may be supplemented with a probabilistic safety assessment (PSA) for fires to identify dominant risk contributors and to balance the options for risk reduction by cost-benefit assessment. The IAEA guidance for performing the assessments is given in References [4, 5, 6].

The design basis for fires [1] is based on defence in depth with confinement of fire damage to a single room. The damage to equipment and cables in the room may have nuclear safety consequences. The safety significance of the fire may be due to

a) the importance of equipment in the room and the extent of its damage; and,
b) the importance of equipment serviced by the cables passing through the room and the extent of the cable damage.

This paper is concerned with the safety significance of fire damage to cables. There can be 50,000 + cables of interest routed through portions of the station. Configuration management for these cable routes is a major challenge for a station. The primary configuration management tool is a cable route database (CRD). It should contain all the necessary information to retrieve the location of the cable along its route from the start device to the end device. It is inevitable that the cable route database will contain latent errors due to the large volume of data that must be maintained.

The importance of latent errors as contributors to operating events and their safety significance has been studied [7]. In an earlier study [8], the potential safety significance of cable routing errors (CREs) was investigated. The thrust of the study was an investigation of sampling methods to determine the residual level of CREs. This is an important datum for risk assessment. This study examines methods to control and reduce the residual level of CREs. The first two levels of defence in depth are

a) to prevent the errors in the CRD; and,
b) to detect and correct errors in the CRD.

Implementing strategies for prevention and correction will minimize the potential impact of CREs on nuclear safety. This can be accomplished with strategies for

a) minimizing the errors made when populating the database during construction;
b) minimizing errors made when design changes are implemented; and,
c) correcting errors found when using the CRD.

The goals can be accomplished by well designed procedures supported by a robust quality assurance (QA) program [9, 10]. Improvement in the quality of cable route information continues throughout the life-time of the station.

In Section 2, existing capability of the cable route locating process (CRLP) is assessed in order to improve process performance quality when the process is under statistical control. In Section 3, the CRLP is controlled to identify and eliminate any special causes that make the process deviate from its target performance quality. A strategic approach is developed to significantly reduce the risk of nuclear safety due to residual CREs during the process, at a cost linked to the quality of creating and collecting, into the CRD, the cable routing information. In Section 4, an effective means, the rectifying sample inspections (RSIS), is defined to control the CRLP to the required accuracy of the CRD for the assessment. In Section 5, documentation and independent review of the assessment are discussed. The CRD is maintained and continuously improved to eventually make the risks insignificant and to be ready for any necessary updates of the assessment. In Section 6, an overall approach for the lifetime of a plant summarizing the methodology in this work is suggested.

## 2. ASSESS THE CAPABILITY OF CABLE ROUTE LOCATING PROCESS

Errors are possible during each procedure of the CRLP as idealized in Figure 1. The ‘matching’ (between cable and cable tray(s)) and ‘routing’ (of cable tray(s)) information for a cable is created at the plant, then read and separately recorded, during the assessment, into a cable route database. The information collected is then verified via plant walkdown before being used.

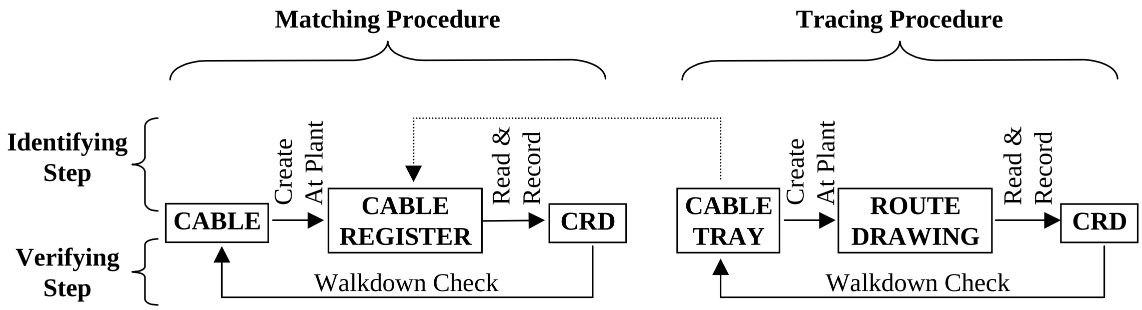


Figure 1 The CRLP model [8]

The number of errors can be reduced through continuous improvement of the process. The improvement can be achieved by reducing variation in process output so that a good process capability, the range over which the natural variation of a process occurs as determined by the system of common causes, is always maintained [11]. The process capability is thus a quality indicator of a process when the process is in statistical control. There are three important components for the process capability, namely, the specification, the centre of natural variation and the range of variation, which are depicted in Figure 2 when applied to a procedure of the CRLP.

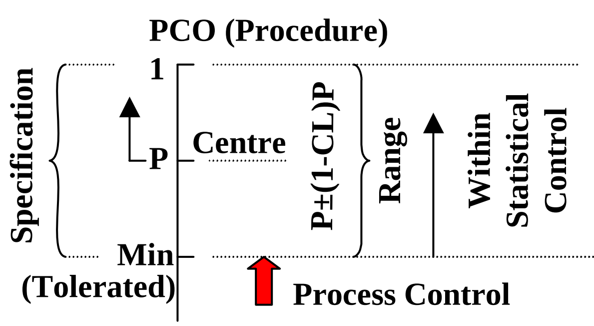


Figure 2 Control and improve a procedure of the CRLP [8]

Here, the procedure is controlled with the parameter, the probability of correct output (PCO) from the procedure. As the process capability improves, the range of natural variation reduces and the centre of the variation moves toward unity (see the line arrows in the figure). As a result, the specified minimum probability tolerated temporarily can be raised, leading to a more accurate CRD for the assessment.

Since it is not feasible to determine a conventional sample-based capability for a procedure of the CRLP, a critical attribute process, the centre and range of natural variation can only be estimated for the procedure according to the associated quality assurance level [8]. Therefore, the centre of natural variation, P, is taken as the average PCO as expected with the existing QA program and training. The range of natural variation is assumed related to the level of confidence as felt by, or seen from, one in performing the work following the QA requirement. Thus, a higher confidence level (CL) would result in a performance quality closely around the average, i.e. a narrower range of variation as calculated with P±(1-CL)P.

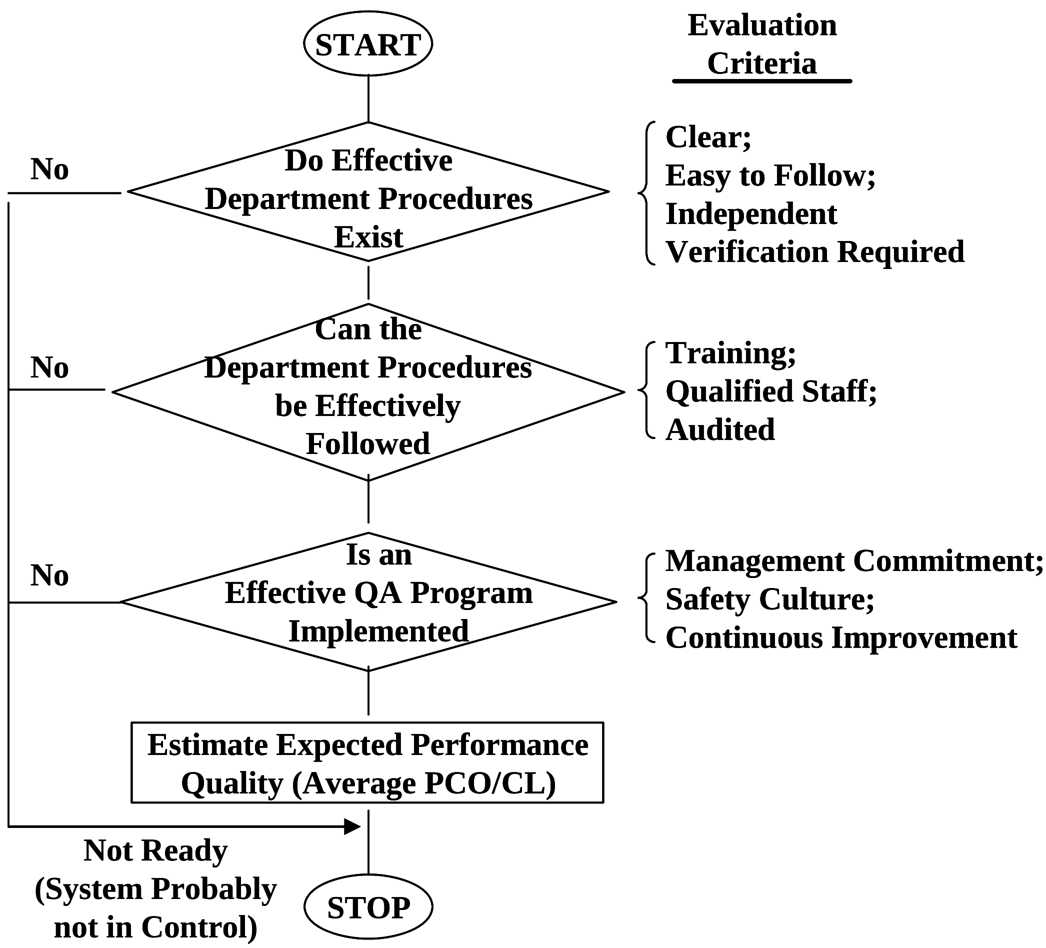


Figure 3 Evaluate expected performance quality for a task

To assess the process capability for each procedure of the CRLP, the effectiveness for all tasks in the process is evaluated, following the flowchart in Figure 3. First, the plant performance quality, respectively for creating the cable-cable tray matching and cable tray routing records (e.g. on cable registers and cable tray drawings), is evaluated. This is based on an analysis of relevant QA documents and department procedures at the plant for conducting the cabling work. For example, a simple and clear instruction leading to fewer mistakes may deserve a high mark. If the ‘matching’ or ‘routing’ record for each cable requires independent verification, the respective performance quality would be further increased considerably. After the evaluation, the plant performance quality is concluded as $P_{p,c}$%/$CL_{p,c}$% (average PCO/CL) with the subscript p = 1 or 2 for the ‘matching’ or ‘routing’ work, and the ‘c’ meaning the creating.

Similarly, the analyst then evaluates their own process, and concludes a performance quality $P_{p,t}$%/$CL_{p,t}$% expected for all tasks involved, with the subscript ‘t’ meaning the task. Referring to Figure 1, the tasks include reading and recording into the CRD the plant ‘matching’ and ‘routing’ information to complete the identifying step, then verifying the respective information for each cable through plant walkdown.

There is a constraint existing between P and CL estimated for performing a task. From Figure 2 also applying to a task, P+(1-CL)P=1 at the upper limit of the range, that is

$$P = 1/(2 - CL) \qquad (2.1)$$

The constraint is better explained in terms of the percent difference between P and CL (Figure 4). In order for the performance of a task to be acceptable, P must be greater than or at least equal to that from Equation (2.1). If not, the evaluation conducted should be examined, or the QA program should be enhanced to raise the QA requirement ‘bar’ to exceed the current confidence level. However, if CL is very high, the constraint can be reduced to ‘at least P=CL’ for practical applications.

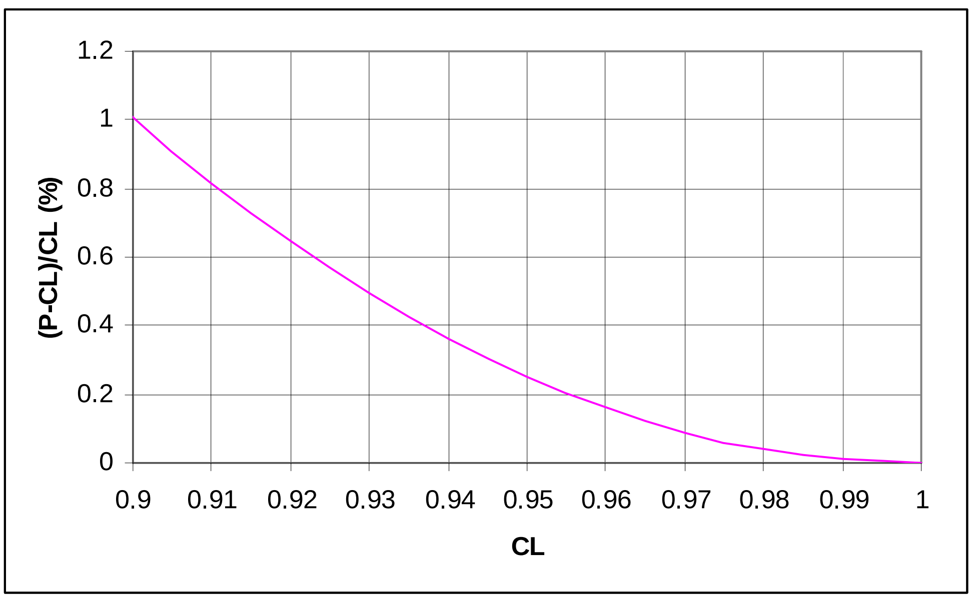


Figure 4 Constraint between P and CL for a process

Equation (2.2) below is used to estimate the probability of correct cable routing (PCCR) expected in the final CRD:

$$P_{CCR} = P_1 x P_2 \qquad (2.2)$$

where $P_p$ (p = 1 or 2) is the probability of correct ‘matching’ or ‘routing’ information in the final CRD. That is, for a cable route to be correct, its ‘matching’ and ‘routing’ information must be correct at the same time. $P_p$ was conservatively derived in Reference [8] at the lower limit of the range of natural variation for each procedure of the CRLP:

$$P_P = P_{P,1}CL_{P,1} + (1 - P_{P,1}CL_{P,1})xP_{P,2}CL_{P,2} \quad (2.3)$$

Here, $P_{p,s}$ and $CL_{p,s}$ are the average performance quality (i.e. the centre of natural variation) and associated confidence level for the matching or tracing procedure (p = 1 or 2) during the identifying or verifying step (s = 1 or 2) of the CRLP. $P_{p,1}$ and $CL_{p,1}$ during the identifying step are solved from the following two equations that combine the ranges of performance quality at the plant and during the assessment:

$$P_{P,1} + (1 - CL_{P,1})P_{P,1} = 1 \quad (2.4)$$

$$P_{P,1} - (1 - CL_{P,1})P_{P,1} = [P_{P,c} - (1 - CL_{P,c})P_{P,c}]x[P_{P,r} - (1 - CL_{P,r})P_{P,r}] \quad (2.5)$$

with the subscript ‘c’ for creating, and ‘r’ for reading and recording. Equation (2.5) is reduced to

$$P_{P,1}CL_{P,1} = P_{P,c}CL_{P,c}xP_{P,r}CL_{P,r} \quad (2.6)$$

Therefore, $P_{p,1}$ and $CL_{p,1}$ are obtained as

$$P_{P,1} = (1 + P_{P,c}CL_{P,c}xP_{P,r}CL_{P,r})/2 \quad (2.7)$$

$$CL_{P,1} = \frac{2P_{P,c}CL_{P,c}xP_{P,r}CL_{P,r}}{1 + P_{P,c}CL_{P,c}xP_{P,r}CL_{P,r}} \quad (2.8)$$

Equation (2.6) shows that the existence of more than one task adversely affects the performance quality of the composite process. For example, if the performance quality is assumed to be 99%/99% for all tasks, from Equations (2.7) and (2.8), $P_{p,1}$ and $CL_{p,1}$ are degraded to 98.03% and 97.99%. This leads to PCCR = 0.9984 as calculated from Equation (2.3) then (2.2), that is, a rate of cable routing errors in the CRD of 0.0016. This is a double of the rate that would be achieved if $P_{p,1}/CL_{p,1}$ were also 99%/99%, i.e. without the degradation. Thus, much stricter performance qualities are required during the identifying step, in this case, 99.5%/99.5% for each component task.

If the PCCR expected in the final CRD, as estimated from Equation (2.2), is below the minimum probability specified for the current assessment, the overall QA program for the CRLP must be improved. Equation (2.3) can be reorganized as

$$P_P = P_{P,1}CL_{P,1} + P_{P,2}CL_{P,2} - P_{P,1}CL_{P,1}xP_{P,2}CL_{P,2} \quad (2.9)$$

This means that, theoretically, the influence of the identifying and verifying steps on the quality of the cable ‘matching’ or ‘routing’ information is equivalent. In the impossible case, absolute correctness during one step would make the other step unnecessary. In practice, though, the verifying step should only play a remedying role in the CRLP, since it demands costly additional resources and is sometimes difficult to complete. Thus, for a new plant, the CRLP improvement should always focus on the plant performance quality. If the cabling work is done at a superior quality in the first place, the pressure on future verification can be significantly reduced. For an existing plant, a superior performance quality on the part of the analyst throughout the CRLP, although always emphasized, is particularly important to compensate for possible ‘poor’ plant performance.

## 3. CONTROL THE CABLE ROUTE LOCATING PROCESS

Referring to Figure 2 (the block arrow), the purpose of process control is to identify and eliminate any special causes that render the process variation out of statistical control [11]. During the CRLP, this is achieved by combining qualitative management measures and quantitative corrective inspections. Various factors contribute as the special causes, which make the CRLP deviate from its QA target as set in Section 2. The worker assigned for a task may have a prolonged period of downtime. The required verification during a procedure is vulnerable to compromise due to time and resource restraints and difficulties in carrying out the work. Eliminating such human-related special causes at the individual procedure level is the most effective control for the CRLP. Figure 5 presents a control flowchart – during the identifying step of the CRLP:

- The control starts with the most essential task, i.e. the cabling work for a new plant. A qualitative control measure for performing the task shall be defined and executed to ensure that the expected target performance quality $P_{P,c}/CL_{P,c}$ is met.

- After collecting the ‘matching’ and ‘routing’ records for all cables within the scope of assessment, the analyst, while sticking to the QA target $P_{P,r}/CL_{P,r}$ set for the reading and recording task, enters the information for each cable in a zone-oriented cable route database. The dates and names of people creating and verifying a cable record, and defects observed on the record itself, are noted in the database.

- Completion of the above two component tasks is not the end of the identifying step during the CRLP. Since the process control for the cabling work can only be qualitative, there is no indicator that the set QA target has been met. The CRD gathering all cable ‘matching’ and ‘routing’ information provides a means to attain a certain degree of confirmation if no signs of special causes are found from the database, assuming that the creation of the CRD has not artificially polished the quality of the cabling work. It should be noted that the ‘confirmation’ here may be less relevant if the assessment is for an existing plant, since the QA requirement used during the cabling work may not be as high as what expected today, even documented. But for the same reason, such 'confirmation' becomes more important for the assessment for an existing plant.

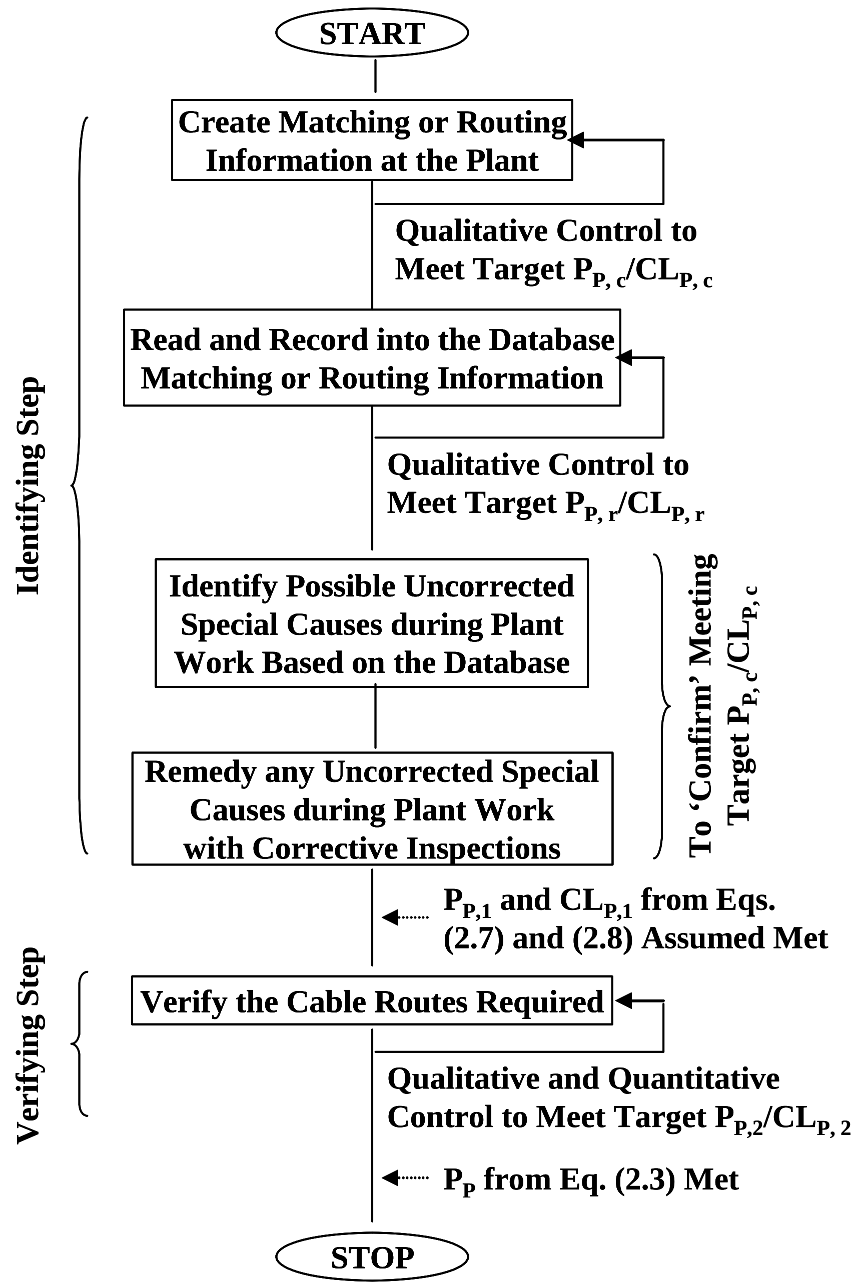


Figure 5 Control of matching or tracing procedures

- To identify possible uncorrected special causes during plant work, each cable in the database is flagged with the QA effort that it received when creating its 'matching' and 'routing' information. For example, if verification was required, but the 'matching' or 'routing' record for a cable was not verified after created, a flag value -1 is given to the relevant entry, otherwise, the default value 0 is assumed. After diagnosing the database systematically, if the cable records during a particular period or related to a particular worker seem a concern, additional flag value -0.1/count for these records are assigned. After all flag values are added up respectively for the ‘matching’ and ‘routing’ entries of each cable, all cables in the database are sorted with the total flag value. The cables with a negative total flag value are considered having been subjected to special causes of varying significance during the ‘matching’ or ‘routing’ work at the plant.

- To bring the ‘matching’ or ‘routing’ entries affected by the identified special causes during plant work back into statistical control, a 100% inspection on all of them is preferred. At least, those affected with severe special causes (i.e. with a large negative total flag value) shall have a 100% inspection. The others, referred to as a ‘weakest link group’, shall pass the rectifying sample inspections as defined in Section 4 to confirm the performance quality expected for them. Then, the required performance quality $P_{P,1}/CL_{P,1}$ for the matching or tracing procedure (subscript p = 1 or 2) during the identifying step, as from Equations (2.7) and (2.8), can be assumed for now having been met.

During the verifying step of the CRLP, the required verification shall be completed. Theoretically, a total verification for all cable routes is required according to the CRLP model in Figure 1, while meeting the set QA target, $P_{P,2}/CL_{P,2}$, through qualitative control measures. This shall be quantitatively confirmed with an acceptance inspection, detailed in Section 4, on the resulting ‘matching’ or ‘routing’ information in the CRD that must meet the expected probability, $P_p$ from Equation (2.3). In practice, total verification is often cost prohibitive. A relaxed and gradual approach with partial verification has to be thus sought in order to eventually meet Equation (2.3). The Pareto principle states that, for many phenomena, the majority of consequences stem from a small number of the causes [11]. That is, the approach shall be also strategic, so that the risk of loss of redundant safety functions due to unrecognized cable routing errors [8] can be equally reduced significantly during the partial verification. The approach follows the steps below:

- Prioritize all systems within the two redundant safety groups at a plant, according to their importance in reducing the above incremental risk. For a system to be critical, it should be relevant to more systems in the safety group that it does not belong to. Another consideration may be to focus on the systems from a same safety group, for example, the group with fewer cables.

- Determine an effective yet viable verification plan for each system, starting from the most critical system. A system with a limited number of cables shall be cleared with a 100% inspection. Otherwise, it shall pass the rectifying sample inspections (RSIS) meeting Equation (2.3) as defined in Section 4. For a critical system that can not afford a total inspection, a tightened RSIS must be designed so that possible CREs can be caught with a reasonable confidence. Thus, the ratio of sample size to population, $NV_s/N_s$, for the system should not be too small for the inspection. For example, from the Discovery Sampling Table [11], if the critical occurrence rate of non-conformance is 0.05% for a population of 2000, the sample size to locate at least one occurrence with a confidence 30% is 600.

- Select the systems for the partial verification. At least, all identified critical systems shall be selected, and then other systems according to the priority list. Every effort shall be made to include as many systems as possible in the verification. The total number of cables to be verified for all selected systems is $NV = \sum NV_s$ leading to a percent verification PV=100xNV/N with N the number of cables in an assessment that are related to the two safety groups. It should be noted that resulting effective percent verification, $PV_E = 100\sum N_s / N$, is greater than the nominal PV, due to the sample inspections involved.

- Perform the partial verification. For management convenience, all inspections on the systems selected can be lumped into three group inspections, i.e. a 100% inspection, a tightened and a normal RSIS. This simplicity will result in an actual percent verification, $PV_A$, somewhat different from the nominal PV. However, the effective percent verification, $PV_E$, always remains the same since it depends on the total number of cables in the systems selected. All inspections shall be carried out separately on the ‘matching’ and ‘routing’ information, per the CRLP model in Figure 1, also since the performance quality during the matching and tracing procedures of the CRLP can be different. For the pairing RSIS’s, the ‘matching’ and ‘routing’ samples shall correspond to same cables to effectively increase the reliability of the inspected cables.

  The RSIS consists of a series of failure-correct-then-repeat sample inspections, with a fresh sample for each run. If an RSIS is successful on its first run, the maximum savings in resources is realized from the RSIS, rewarding the excellent performance for relevant systems during the identifying step of the CRLP. As the number of runs for each RSIS increases, the ratio of $PV_A/PV_E$ for the partial verification approaches to unity (all 100% inspections), consequently, the margin of savings through the use of sample inspections diminishes.

- Accept the cable route database. The foregoing strategic partial verification also mitigates the residual statistical risk, as seen in next section, during the acceptance inspection on the entire CRD. If the database passes the acceptance RSIS on its first run, the maximum savings hopefully claimed as above during the partial verification is extended, further rewarding the excellent job done throughout the identifying step. As the number of runs for the normal RSIS increases, the ‘wishful’ partial verification would approach a ‘punitive’ total verification. Hence, it is evident that substantial savings during the CRLP can only originate from the cabling work at the plant that has to be completed anyway.

## 4. INSPECT THE CABLE ROUTING DATABASE

Inspection is a means of process control during the CRLP. Thus, an inspection shall never be terminated prematurely, during which all CREs found shall be corrected. If a sample inspection on a group of cables fails, e.g. on the 'weakest link group' found during the process control on the identifying step, it shall be repeated with a new sample of same size collected from the un-inspected entries within the same group. Such a series of sample inspections is referred to as the rectifying sample inspections (RSIS). The RSIS can be applied to any critical system identified to individually enhance the reliability of the system.

The RSIS can be also applied to a group of systems with similar importance in reducing the potential risk of loss of redundant safety functions due to CREs [8], as discussed in Section 3 for the strategic partial verification during the verifying step. Accordingly, an RSIS can be normal or tightened. Its sample is collected proportionally from all systems within the group being inspected, based on the number of cables in each system, as long as a system still has un-inspected cables. If a system has run out of un-inspected cables during a group RSIS, either the system has a very limited number of cables (then it should be cleared with a 100% inspection in the first place), or it may indicate that the quality of the system group being inspected is poor.

A normal RSIS on all systems in the CRD is performed as the acceptance inspection that is the final control measure on the total or partial verification during the verifying step of the CRLP. The RSIS is conducted respectively on the general 'matching' or 'routing' information in the CRD. It confirms the database for acceptance with a maximum rate of CREs also improves the overall accuracy of the database. Following a partial verification, only the un-inspected entries within each system in the database are sampled for the two general inspections – this further tightens up the quality of the 'weakest link group' and the critical systems that have undergone separate RSIS.

A sample inspection consists of three steps, select an acceptance sampling plan from a standard for attribute lot sample inspection, determine a sample from the 'matching' or 'routing' population in the CRD that is to be inspected, then verify the relevant cable information in the sample by plant walkdown. The sample is proportionally selected from all subgroups in the population (e.g. each zone, system, period or person as applicable) – this is done with the sorting capability built in the database. All cables in the sample shall be verified – if walkdown is not possible, special techniques shall be resorted to. Each 'matching' or 'routing' entry verified is assigned a flag value 1 (default zero), under a new column heading for the analyst, for future reference. After all sample inspections for the current assessment are completed, all subgroups should be analyzed for possible new 'weakest link group', which, if any, shall be reinforced with a follow-up RSIS.

The acceptable quality level (AQL) sampling plan [11] is chosen for the RSIS. As illustrated in Figure 6 with a typical operating characteristic (OC) curve for an acceptance sampling plan, the AQL plans accept, with a high probability, the lots produced from a process with an average performance quality of (1-AQL). This is consistent with the fact that great care has been always exercised during the CRLP so that the process quality is quite stable. Nevertheless, precautions are needed since each lot inspected here is considered isolated – once it passes the inspection, there is little chance during the current assessment to remedy possible escaped defectives. Thus, a limiting quality (LQ) and an associated consumer's risk at the LQ shall be applied during the AQL inspections. This is to ensure that, while statistically the non-conformance rate of any similar lot is at the AQL, the maximum probability of the particular lot, being inspected, with a lower quality of the defective rate ≥LQ to pass the inspection is at a level agreed by the consumer – the users of the FHA or fire PSA.

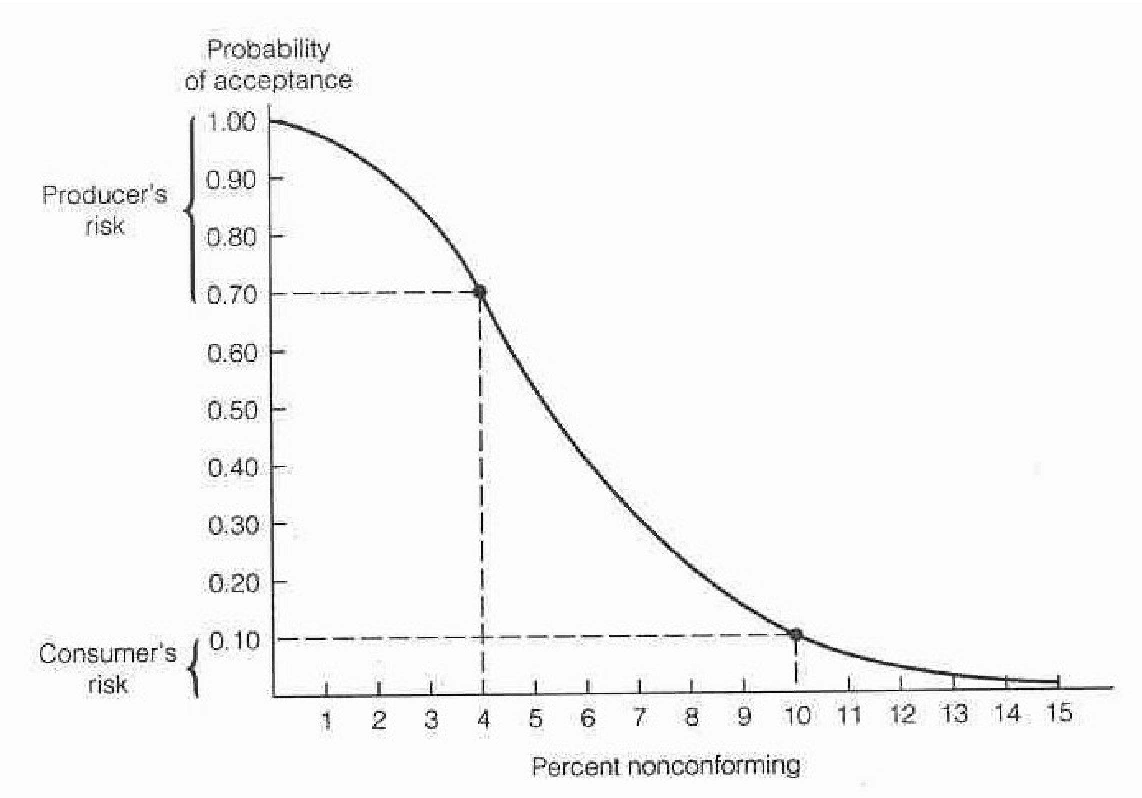


Figure 6 Typical OC curve for an acceptance sampling plan [11]

In fact, for application to the sample inspections on the CRD, the LQ is only of symbolic significance. For example, if the LQ for a lot of 15000 'matching' entries in the database is assumed 1% with a 5% consumer's risk at the LQ, for a single sampling plan (preferred) and at normal inspection level, the required AQL of the lot is about 0.04% [12]. This corresponds to an average probability of correct output 98% for the matching procedures during the CRLP, i.e. 1-[0.98+(1-0.98)x0.98]=0.0004. While the resulting average performance quality of 98% seems reasonable, the level of consumer protection chosen is apparently too low thus meaningless. The protection will become relevant if the LQ and associated consumer's risk are sufficiently tight, but this will make the sample inspection very demanding. However, specifying an LQ will always reinforce consumer protection by limiting the minimum sample size that can be used in the AQL inspection.

If the minimum PCCR accepted by an assessment is $P_{CCR,\ Min}$ from the CRLP, the minimum probability of correct output from either the matching or tracing procedure of the process is assumed $(P_{CCR,\ Min})^{1/2}$, which always imposes a conservative requirement for the worst of the two procedures. Since the minimum probability $(P_{CCR,\ Min})^{1/2}$ is meant at the lower limit of the range of natural variation for the procedure, the average PCO for either procedure is then $(P_{CCR,\ Min})^{1/2}/CL_{p,\ Ova}$, with $CL_{p,\ Ova}$ the overall confidence level for either procedure. Therefore, the maximum AQL for all sample inspections on the CRD can be set as:

$$AQL_{Max} = 1 - P_{CCR,Min}^{1/2} / CL_{p,Ova} \tag{4.1}$$

With a given minimum level of consumer protection for all sample inspections, the required AQL for each lot may be different but must be lower than $AQL_{Max}$ when selecting a sampling plan for the lot. The overall procedure confidence level $CL_{p,\ Ova}$ can only be estimated. As discussed in Section 2, since $CL_{p,\ Ova}$, combining $CL_{p,\ 1}$ and $CL_{p,2}$ in a way similar to the right hand side of Equation (2.3) when all P's =1, is usually very high, it can be assumed to equal the corresponding $P_{p,\ Ova}$. Thus, $P_{p,\ Ova}CL_{p,\ Ova} = CL^2_{p,\ Ova} = (P_{CCR,\ Min})^{1/2}$, i.e. $CL_{p,\ Ova} = (P_{CCR,\ Min})^{1/4}$.

## 5. DOCUMENT AND MAINTAIN A VALID CABLE ROUTING DATABASE

Even if the CRD has passed the acceptance inspections, it may not be very satisfactory to the analyst, for example, access to all desired zones at the plant is always a concern. Conservatism shall be then applied in the assessment to any uncertain cable routes, which shall be documented for future resolution. The documentation shall also include how the process capability of the CRLP was assessed, and how the process was controlled to meet the required minimum PCCR. The corresponding maximum rate of CREs and the associated risk on plant safety, i.e. the probability of loss of redundant safety functions [8], shall be reported in the assessment for management purpose.

The assessment is reviewed by an independent reviewer. If necessary, the rectifying sample inspections on the CRD are repeated to confirm the accuracy of the database claimed. Only the un-inspected entries in the CRD are sampled from all subgroups in the database for the two general inspections. If a partial verification was done for the original assessment, this continues to tighten up the quality of the 'weakest link groups' and the critical systems, in the meantime, enhance the overall confidence on the database. All entries verified are flagged with the value 1 (default 0), under a new column heading for the reviewer, for future reference. Any CREs found are corrected and reported to the analyst for revising the assessment. The review work is also documented.

The analyst continues to maintain the CRD on behalf of the plant. The 'matching' and 'routing' records for all cable rerouting and new routing, and other relevant information, are updated or added, similar to what done when the database was created. If the analyst finds any deviations of the records from the plant QA requirements that may have been improved upon recommendation after last assessment, he/she shall immediately take control actions for the process. To mitigate the residual statistical risk associated with sample inspections through which the database was accepted, the analyst also improves the CRD on regular basis as CREs are found during use of the CRD for station work. The flag values accumulated for all cables in the CRD can be analyzed to identify new critical systems. The new and old critical systems can be strengthened through 'fixing' up previously un-inspected cables. Any new CREs found during the maintenance shall be corrected. For future reference, all cables verified are flagged under a new column heading for the maintenance.

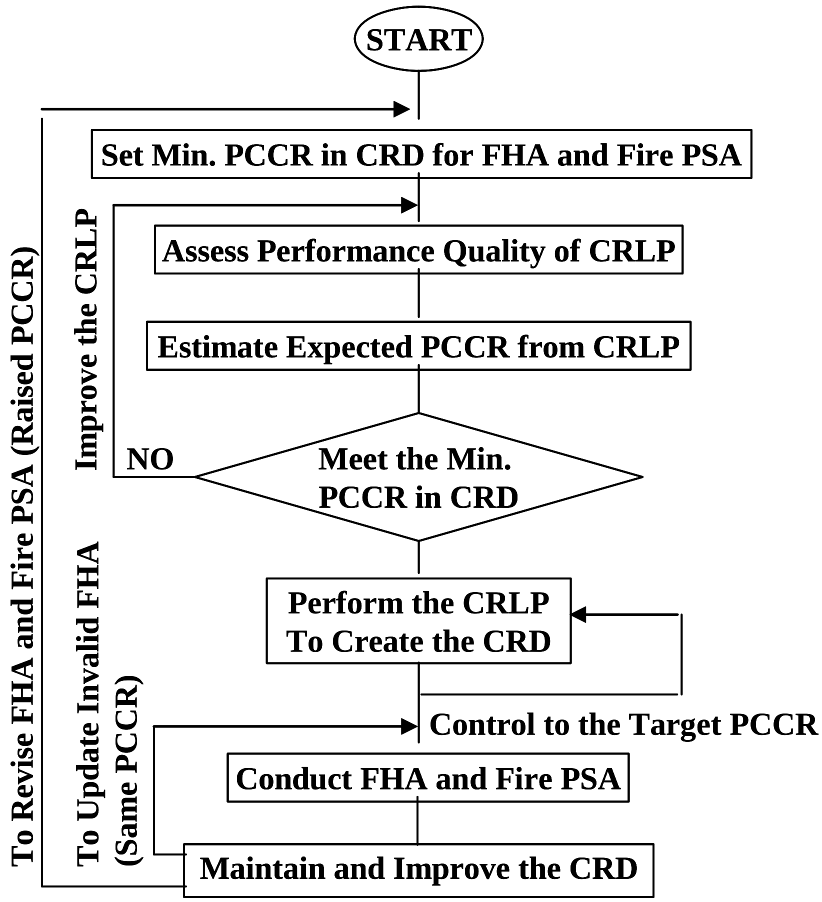


Figure 7 Reduce the possibility of CREs over the lifetime of an NPP

If the last FHA becomes invalid due to the new, revised or corrected cable routes in the current CRD, it shall be revised in time. Such limited change in the CRD, statistically, will not affect the reported risk on the plant safety due to CREs. Thus, there is no need to revise the fire PSA for the plant covering this incremental risk. However, if the risk is later considered too high, the CRLP must be repeated to target a higher minimum PCCR in the CRD specified for new FHA and fire PSA. During the new CRLP, the identifying step takes $P_{p,\,1}$ = 1-$AQL_{Max}$ and $CL_{p,\,1} = CL_{p,\,Ova}$ in Equation (2.3). The verifying step follows what described in previous and current sections – the cables in a given system not verified by now shall be selected first during relevant sample inspection.

## 6. CONCLUSIONS

The large volume of data required for the location of cables will inevitably contain errors. These latent errors have the potential to compromise nuclear safety (FHA and fire PSA). A three-way strategy was suggested to address this incremental risk [8]: to include the risk in the fire PSA, to mitigate the risk with conservative and proven measures in the FHA, and to continuously limit the risk by reducing the possibility of CREs over the lifetime of the plant. In this work, a methodology is developed to implement the third approach as depicted by a 'non-stop' overall flowchart in Figure 7. It employs strategic partial verification during the verifying step of the CRLP, with the rectifying sample inspections as an effective means to control the process and, thus, the accuracy of the resulting CRD. The strategy not only can reduce significantly the risk due to CREs, but also the cost of cable route verification during the CRLP.

## LIST OF ACRONYMS

| | | | |
|---|---|---|---|
| AQL | Acceptable Quality Level | NPP | Nuclear Power Plant |
| CL | Confidence Level | OC | Operating Characteristic |
| CRD | Cable Route Database | PCCR | Probability of Correct Cable Routing |
| CRE | Cable Routing Error | PCO | Probability of Correct Output |
| CRLP | Cable Route Locating Process | PSA | Probabilistic Safety Assessment |
| FHA | Fire Hazard Assessment | QA | Quality Assurance |
| LQ | Limit Quality | RSIS | Rectifying Sample Inspections |

## NOMENCLATURE

| | |
|---|---|
| $AQL_{Max}$ | Maximum AQL set for all sample inspections on the CRD |
| $CL_{p,\ Ova}$ | Overall confidence level of the two steps of the CRLP, subscript p = 1/2 for the matching/tracing procedure |
| $CL_{p,\ s/t}$ | Confidence level expected from a process, subscripts p = (see above) and s = 1/2 for the identifying/verifying step of the CRLP, t = 'a task', e.g. t = c/r for the creating/reading & recording task during the identifying step |
| N | Number of cables, in an assessment, related to the two safety groups at a plant |
| $N_s$ | Number of cables in a system |
| $NV_s$ | Number of 'to be verified' cables in a system during an inspection |
| $P_{CCR}$ | PCCR from the CRLP, thus in the resulting CRD |
| $P_{CCR,min}$ | Minimum PCCR accepted by an assessment |
| $P_p$ | PCO after the two steps of the CRLP, subscript p = (see above) |
| $P_{p,\ Ova}$ | Overall average PCO of the two steps of the CRLP, subscript p = (see above) |
| $P_{p,\ s/t}$ | Average PCO expected from a process, subscript p/s/t = (see $CL_{p,\ s/t}$) |
| PV | Nominal percent verification during a partial verification |
| $PV_A$ | Actual percent verification during a partial verification |
| $PV_E$ | Effective percent verification during a partial verification |

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