# A Reliability Study of Commentary Systems used at Football Matches

**By**

**TAWANDA VICTOR MUTSHIYA**

**27273832**

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## Executive Summary

In broadcast commentary there is a small margin of error as coverage is usually to a live audience of millions of sport fanatics entailing micro second delays between the live coverage and what viewers at home see and experience. The purpose of this project is to therefore study the Reliability of the Commentary System and its constituent subsystems that are responsible for broadcasting audio and video signals that viewers see and hear.

The scope of this project encompasses a complex commentary system composed of the following three subsystems

- The Stadium Subsystem
- International Broadcast Centre Subsystem
- The Home Country Subsystem

The subsystems are in themselves composed of other subsystems which are subsequently composed of various components whose reliabilities are the basic building blocks of the reliability study of the entire commentary system.

The study rides on the data collected from commentary systems used at the 2010 Football World Cup and provides an in-depth look at the complex arrangement of constituent components. Human reliability is a key factor for a successful broadcast and owing to a number of key issues addressed in the project the human-machine interfaces at varying levels of the commentary system have not been analyzed separately but instead treated as part of a whole.

The practical value of Reliability information includes a positive correlation with cost control, an evaluation of the likelihood of success and improvement opportunities incorporated into the system as a whole.

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# List of Abbreviations

AEG – Active Element Groups

BIF – Basic International Feed

CCU – Commentary Control Room

CMR – Commentary Matrix Rack

COORD – Coordination wire

CS – Commentary System

CSC – Commentary Switching Centre

CU – Commentary Unit

DS – Down Synchronizer

DC – Digital Converter

EBIF – Extended Broadcast International Feed

HBS – Host Broadcasting Services

HP – Highlights Production computers

IBC – International Broadcast Centre

ITR – Intercom and Trunking Rack

MCR – Master Control Room

MS – Matrix Switcher

MTBF – Mean Time between Failures

MULTI – Multilateral feed

OB - Outside Broadcasting Van

PGM – Program circuit

TOC – Technical Operations Centre

UNI – Unilateral feed

# 1. Introduction

Football has an ever growing international popularity; its enormous appeal and its expanding economic, social and even political significance have made it a vital common denominator in a variety of people from different walks of life all across the world. The massive interest and popularity in the sport can be attributed to the direct result of television coverage. Companies such as the Host Broadcasting Services (HBS) are responsible for the production and transmission of audio and video feeds of live football matches that are viewed all across the world.

To achieve this when there is an International football tournament of the magnitude of the World Cup, HBS will design, build, install and manage an International Broadcast Center (IBC) as well as all broadcast facilities at the various stadium venues. When put together all these facilities form a complex Commentary System (CS) whose reliability is the focus of this study.

One of the most important design parameters in any complex system is reliability. The reliability of the commentary system can be defined as:

*The probability that the system will adequately perform its specified purpose of enabling video and sound output for a specified duration of a football match under prevalent environmental conditions.*

For the successful propagation of the audio and video signal it is of vital importance that the performance of all commentary subsystems and their subsequent components be efficient and effective with high reliabilities. The biggest advantage in determining the reliability in such a football environment is that once the reliability is ascertained for each purpose, the maximum possible safety initiatives can be built into each component, cost control is better managed and the likelihoods of success are known and failure rates mitigated as far as possible

Much of the data and literature is derived from the Commentary Systems used at the 2010 Soccer World Cup in South Africa.

## 2. Project Aim

In broadcast commentary there is a small margin of error since the coverage is usually to a live audience of millions of sport fanatics entailing micro second delays between the live coverage and what the viewers at home see and experience.

The aim of this project is to determine the reliability of the Commentary System (CS) by studying the contributing components to the successful propagation of a live audio and video feed to millions of viewers across the globe.

## 3. Project Scope

The main objective of the commentary system is to feed video and sound to broadcasters' home countries through the adequate performance of the following subsystems shown in figure 1 below.

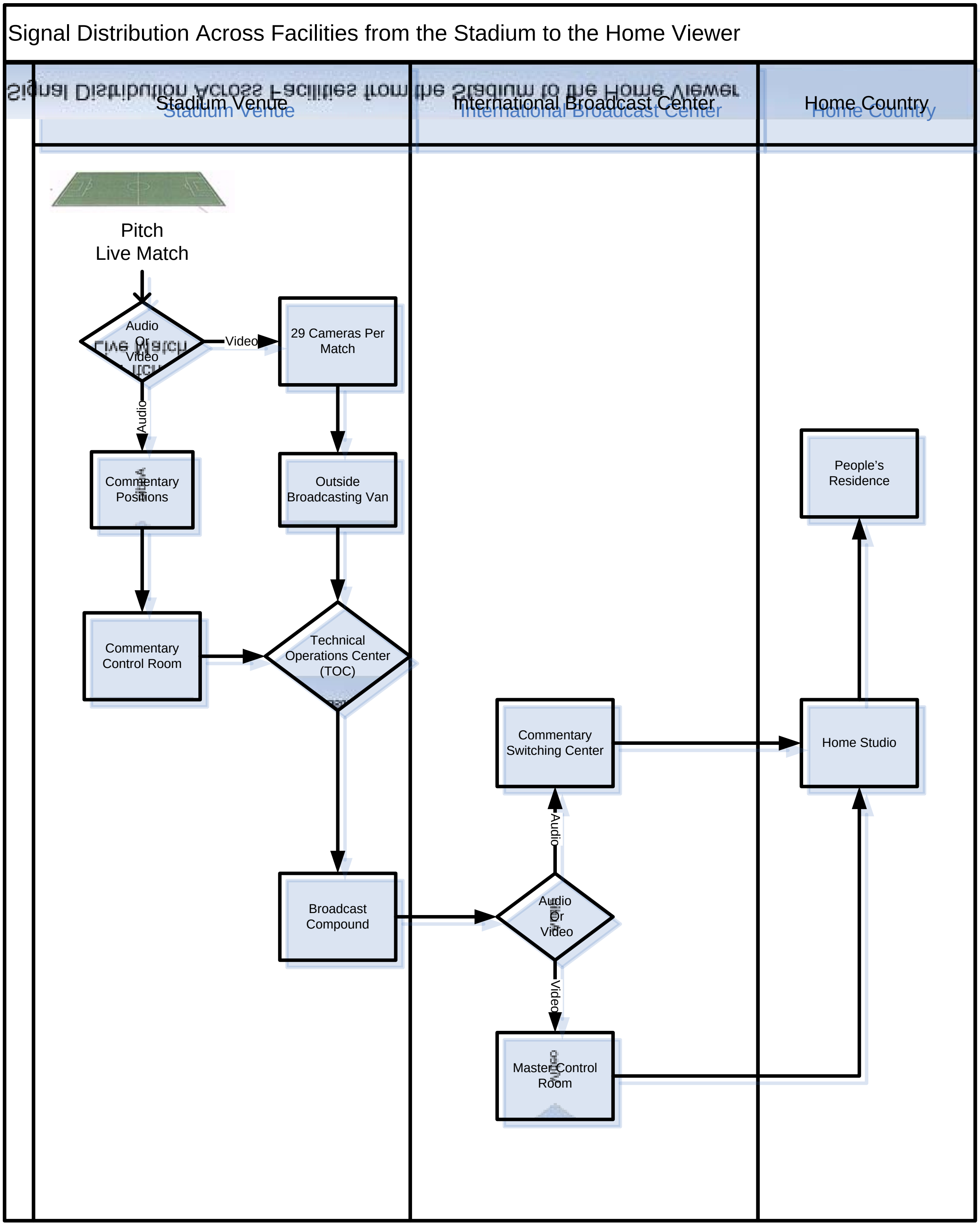



**FIGURE 1: A Cross functional flowchart of the Commentary System Constituents**

Match coverage of high profile Football Matches of the calibre of the Football World Cup include approximately 29-32 cameras. The images and sound captured by the cameras pass through a number of key stages before reaching home viewers on their television and radio sets at home.

From the cross functional flow chart in figure 1 above:

- pictures are transmitted live from the field of play to the Outside Broadcast(OB) vans in the Stadium compound where a Basic International Feed(BIF) is created
- From the OB vans signals are sent to the Technical Operations Centre(TOC)through cables with a satellite feed also sent as backup at the Broadcast Compound
- From the Broadcast Compound the signal is sent to the International Broadcast Center(IBC) via fibre optical cables with a satellite feed also used as backup
- At the stadium commentators broadcast their own live audio commentary feed to the local Commentary Control Room(CCR)
- From the CCR the feed is sent to the TOC then to the IBC via fibre optics for switching and passing onward to home studios
- At the IBC the Master Control Room (MCR) and the Commentary Switching Center (CSC) manage all incoming video and audio circuits. The signals are monitored, routed and distributed to broadcasters who have their own facilities at the IBC.
- At this point in the IBC, a world feed distribution is generated which transmits the broadcast video and sound material via satellite to each continent
- At the Home Countries the feed is received, customized and sent via satellite or fibre optics for home viewing

The successful broadcast of a football match therefore requires successful operation of the units in the three main subsystems noted

- The Stadium Venue Subsystem
- International Broadcast Centre Subsystem
- Home Country Subsystem

Each of which have relevant subsystems as shown in preceding sections

# 4. Reliability Methodology (Literature Study)

## 4.1 Introduction

The purpose of this literature study is to convey to the reader what knowledge and ideas have been established regarding the scope of this particular project and stating the strengths and weaknesses of Reliability Analysis. The purpose also includes equipping the student in making informed decisions about the aspects of reliability analysis that will find relevance in the project.

## 4.2 Definition

Reliability can be defined as the probability that the system (Commentary System) will adequately perform its specified purpose (enabling video and sound output) for a specified duration (of a football match) under prevalent environmental conditions. Leemis (1995, pp. 2)

Reliability is a facette of Quality Assurance in Industrial Engineering that concerns itself with various inanimate objects as Light bulbs or drill bits. When looking at a complex system, it is considered as a collection of components that are arranged in a structure that allows the system state to be determined as a function of the component states.

Reliability could be a performance requirement, or it could be broken out separately. It is normally given as a mean-time between failures or as an operability probability.

## 4.3 Reliability as a mean-time between failures (MTBF)

Mean Time between Failure (MTBF) is a measure of reliability defined statistically as the number of hours a component, assembly or system will operate before it fails.(Computerworld, 2010)

MTBF values can be predicted using the following techniques:

- Prediction based on the analysis of similar equipment which is normally used in instances where there is lack of data. The prediction uses MTBF values of similar equipment with similar reliability characteristics
- Prediction based on an estimate of Active Element Groups(AEG) where the smallest functional building blocks are estimated as a count using complexity factors to predict MTBF

- Prediction based on an equipment parts count where a design parts list is used to classify parts into specific categories where failure rates are then assigned  and combined to provide a predicted MTBF value for the system
- Prediction based on stress analysis which states that when a detailed equipment design is relatively firm, predicting the reliability becomes sophisticated as part types and quantities are determined, failure rates are applied with stress ratios and environmental factors considered.

Blanchard et al (1998 pp. 356-357) states that MTBF analysis is only used for those components that are repairable and can be returned to service.

## 4.4 Reliability as an Operational Probability

Reliability as an operational probability involves observing the system being used in a realistic environment, reflecting a true assessment of the system reliability. The assessment of system reliability in an operational environment is best accomplished through the establishment of effective data collection, analysis and a system evaluation capability. Blanchard et al (1998. pp 356)

The purpose of this is two fold:

- To provide ongoing data that can be analyzed to determine the true reliability of the system while performing its intended mission
- To provide historical data that can be beneficially used in the design and development phase of new systems and equipment having a similar function and nature. Such data is paramount to the facilitation of accurate analysis and predictions in the future.

Of the success and maintenance data elements that are considered important for a system as a whole, operational status and condition of the system at specific points in time, maintenance requirements necessary to restore the system to full operational status and details associated with the actual cause of the failure and the effects on other elements in the system are of specific interest to the reliability analysis.

These data should be collected throughout the system operational cycle to the maximum extent possible, and analyzed to determine trends and inherent weaknesses in the system so as to enable areas of deficiency to obtain necessary modifications.

## 4.5 Electronic Reliability Prediction

In his work on electronic reliability, Fuqua (2010) states a number of ways used to predict the reliability of electronic equipment.

- Similar item /Circuit Prediction

  This prediction method begins with the collection of past experience data on similar products which is then compared and contrasted for form, fit and function compatibility with the new product. If the product does not have a direct similar item, then lower level similar circuits can be compared where data from component circuits is collected and a product reliability value calculated

  The advantages of using this prediction method is that: it is the quickest way to estimate a new product's reliability and is applicable when there is limited design information.

  The disadvantage however is that most new products are substantially different from past similar items resulting in inaccurate predictions

- Prediction by Operational Translation

  Based on the fact that failure rate prediction models derived from empirical models yield estimates that deviate to an appreciable extent from the actual observed failure rates. Operational Reliability differs from the predicted reliability because empirical models only assess component reliabilities and the reliability of systems in operation includes all failure causes, induced failures, inadequate design problems, system integration problems, manufacturing defaults etc.

  The advantages of this prediction method include the ease of its use and the application of environmental factors for harsh conditions

  A disadvantage is the lack of updated data as well as a limited number of translation scenarios

- Empirical Model Prediction Techniques

  This method varies as empirical data is collected from different sources and environments. Empirical models are those that have been developed from historical reliability data from either field applications or laboratory tests; hence their relevance is a function of the specific empirical prediction methodology used.

The advantage of this method is the ease of its use as various models for components exist. A disadvantage is that the data base may be based on outdated data that is no longer applicable resulting in inaccurate estimates for new technology components

## 4.6 Confidence Levels of Predictions

In general a reliability prediction cannot be linked to a specific confidence interval. This is largely due to the following factors. Pecht (1990):

- Reliability Prediction Models are based on data collected from a variety of sources and complete models can never be developed from a single data source
- Human variability factors in making prediction assumptions, analyzing the data and in failure definitions also make it difficult to come up with a confidence interval.

## 4.7 The Broadcast Environment

A broadcast system is a system of components that can be defined as binary. Gertsbach (2000) points out that a binary component is a component having only two states, an operational and a failed state.

For the purposes of this study it is assumed that during the duration of a football match. The commentary system can only be in two states

- Operational when the video and sound feed are successfully propagated to the home viewer from the stadium and
- A Failed state when the video and sound feed or either one fail to reach the home viewer and there is a loss in transmission

The dependence of the broadcast system's state on the state of the components can be determined from a set of functions, quantified as the Reliability of the system.

## 4.8 M out of N systems

An M out of N system is a system in which only at least M out of its N components can be operational to define the system as functional Leemis (1995). This is however only possible for a parallel configuration for which the system component states are independent of the state of the other components. In a series arrangement, using broadcast commentary as an example, the feed has no alternate paths hence if the state of one component is such that it is in Fail then the other subsequent components also fail to propagate the signal as they are dependent on the Failed system to pass on the signal.

When looking at M out of N systems in the context of Broadcast Commentary the best example is that of the Commentary Unit – Commentary Control Unit subsystem as shown in the Figure below adapted from the Commentary Assistant workbook:

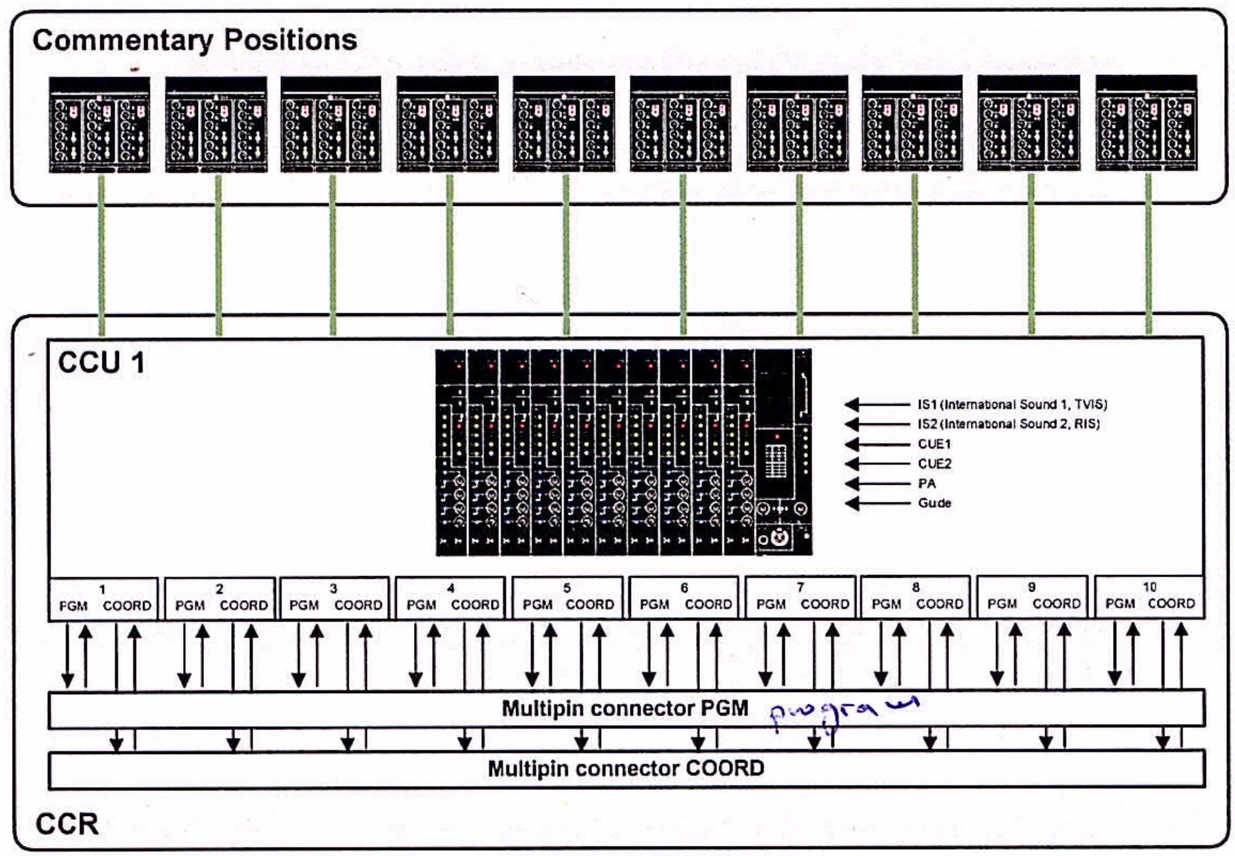



**FIGURE 2: Commentary Unit connections to the Commentary Control Unit**

AS can be seen from figure 2, a single Commentary Control Unit (CCU) takes in 10 Commentary Units (CU). For the CU-CCU subsystem to remain operational at a satisfactory level, it has to have a minimum of at least 8 Commentary Units Operational. The CU-CCU subsystem is therefore dubbed an 8 out of 10 system and will only be said to provide a satisfactory performance when eight out of 10 of the Commentary Units are fully operational. Below that value of 8 operational CUs the subsystem is said to have failed.

## 4.9 Failure Categories in Reliability Analysis

The main challenge faced by any system is to enhance the reliability of its components whilst minimizing the possibility of malfunctions.

According to Enrick (1985), a sound evaluation of reliability begins with a consideration of the types of failures that may be encountered and these are classified into three main categories:

- Early Failures

  These are failures resulting from defects in production usually prevalent at the start of the use of the product/component. These are frequently mitigated by debugging and testing out equipment for operational inefficiencies before the intended purpose.
- Chance Failures

  These are failures that occur at various intervals of the lifecycle of a system component or equipment. Hidden defects that may have not been detected and classified as an early failure may be the chief culprits to this type of failure as well as the impact of environmental stresses such as electrical, magnetic, temperature and vibrations. According to Enrick (1985) the rates of these failures have been studied extensively for many components, subsystems and equipments and it has been found that the rates of such type of failures are very low.

  The failure of one small component in broadcast commentary amongst the multitude of other components may bring about a system failure as the propagation of a live video and sound feed may be disrupted.
- Wear out Failures

  These are failures that come about as a result of prolonged usage and the effects of wear interfere with the intended applications of an object.

In broadcast commentary chance failures are the most prevalent. Severe testing is always done as the operational efficiencies of each vital component have to be above par. However the times when a live feed goes dead or there is a loss in sound, chance failures are the main culprit and more often than not technicians' battle to rectify the cause due to the nature of their occurrences at random intervals.

Wear out failures particularly on sensitive equipment as the commentary unit earphones are common and have necessitated ready back up components that are kept in the Commentary Control Rooms

## 4.10 Practical value of Reliability Information

The following Fishbone diagram highlights the practical value of Reliability Information

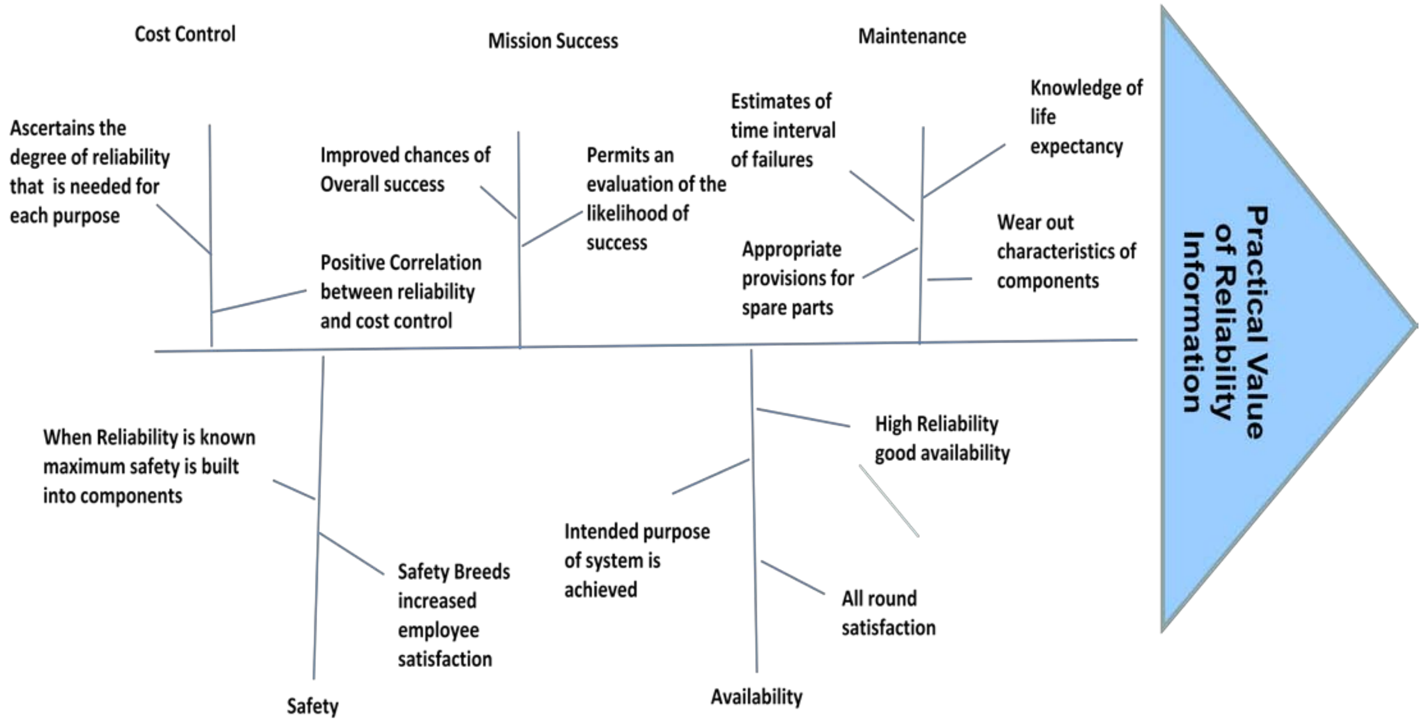



**FIGURE 3: A Cause and Effect Diagram of the Practical Value of Reliability**

Once the Reliability of the System has been determined, some of the benefits derived are as shown in the figure 3 above.

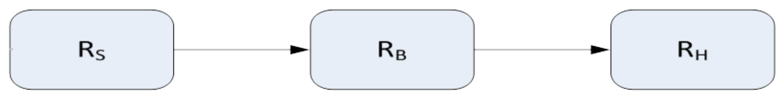
## 4.11 Practical Precautions of Reliability

When considering reliability, the assessment should be at all times consistent with the underlying failure distribution which in most cases, though always pending a testing procedure will always follow some type of normal distribution. Gitlow et al (2005)

A number of assumptions are frequently made when considering failure analysis of system components. In most cases it is assumed that a period of constant failure is identified and that constant forces of failure are prevalent that are the main culprits

## 5. Reliability Modeling and Design

The Reliability of the whole commentary system can be modeled as the Series Reliability of the subsystems shown in Figure 4 as shown below:




Stadium system IBC system Home studio system

**FIGURE 4: commentary system constituent systems**

The two wires in parallel, the coordination and program wires extend through the system enabling feedback functions. The stadium system involves the location where audio and video signals originate. The signals are propagated through a variety of subsystems within the stadium system that include:

- The Commentary Positions
- The Commentary Control Room
- The Technical Operations Centre
- The Commentary Interface Room

From the stadia the signals are sent via fibre optic cables made redundant by satellite feeds to the International Broadcast Centre System. In the IBC signals are propagated through the following subsystems

- The Master Control Room
- The Commentary Switching Centre

The feed is then combined and sent to the various television broadcast studios across the world, whose reliability will be denoted by $R_H$ and also whose scope is beyond that of this study.

Reliability of the commentary system is entirely dependent on the functioning of this system and is significantly influenced by the impact of human reliability factors as human-machine interfaces are prevalent throughout the entire system.

## 5.1 Human Reliability Analysis

The commentary system is largely dependent on interfaces where technicians and other skilled personnel operate on various subsystems. Thus the human reliability element is a key factor for a successful broadcast. When looking at Human Reliability a number of key issues in determining the reliabilities surfaced:

- Existing empirical data was insufficient to support quantitative predictions of human performance in a system as complex as the commentary system
- Expert Judgments on human reliability factors have provided in the past unsatisfactory and inaccurate predictions. Hollnagel(2005)
- In the case of the treatment of important factors that shape performance with respect to the commentary system there was very little emphasis on those related to management, organization and culture as a number of professionals involved in the study where all from different backgrounds bearing different approaches on the same system to provide a collective goal of joining together the different subsystems of the commentary system to propagate the audio and video signals.
- The human-machine interactions in the commentary system are tightly coupled with some composed of complex interactions. This has led to a viewpoint of that the technicians and commentary components being seen as interacting parts of the overall system.
- The actions of technicians was not simply a response to external events, but pried on their beliefs on the current state of the commentary system components. Since the technicians made use of their experience and knowledge, their beliefs at any given points in time where influenced by past events on the system and earlier trains of thought
- In addition the technicians and various users of the commentary system rarely worked alone and where part of a team. In reliability context this means that the technicians' actions are a result of beliefs and cognition rather than simple responses to events influenced by environmental factors and that these beliefs may be shaped and shared to various degrees by the group.

Consequently actions undertaken by all the technicians and users at varying levels of the commentary system have not been analyzed separately but instead treated as part of a whole.

## 5.2 The Program and Coordination Circuits

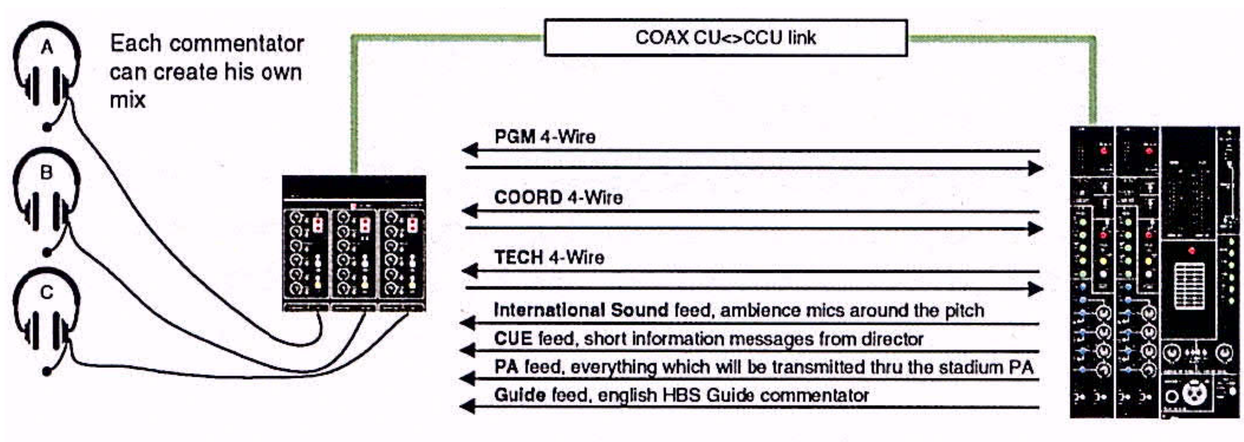



**FIGURE 5: Feeds between a Commentary Unit(CU) and a Commentary Control Unit(CCU)**

Between a commentary unit and a commentary Control Unit and all through the CS up until the home studio there are two 4-wire circuits the program circuit(PGM) and The Coordination Wire Circuits(COORD) that exchange signals and data through the commentary system. The Technical 4-Wire circuit only exchanges data and signals between the CU and CCU and cannot be extended further as it is used only in instances of technical necessity.

The Reliabilities of the PGM and COORD circuits (denoted as $R_{wires}$) that extend all through the system past the IBC up to the home studio are modeled as series components of the overall system and their functions are as follows:

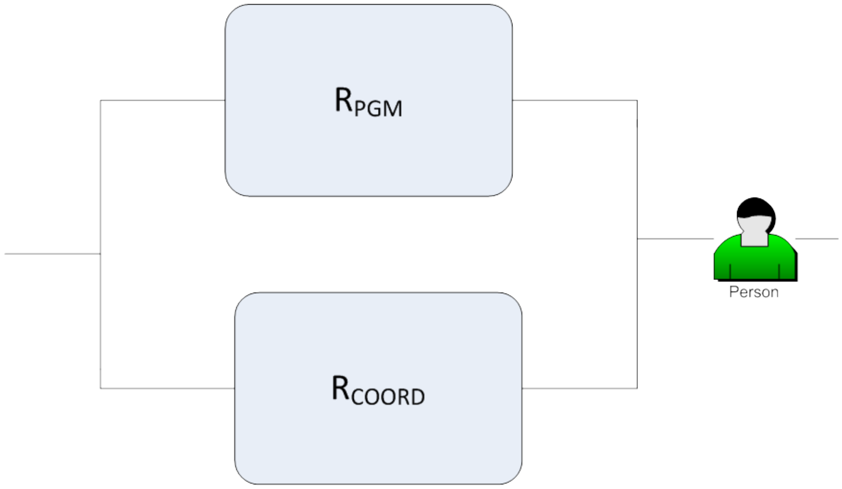



**FIGURE 6: Program and Coordination Wire Configuration Model**

Let

$Q_{PGM}$ be the probability of failure of the program wire

$Q_{COORD}$ be the probability of failure of the coordination wire

$P_{PGM}$ probability of success of the program wire

$P_{COORD}$ probability of success of the coordination wire

$P_P$ Reliability of the technician

$\mathbf{R_{WIRES}} = [1-(Q_{PGM} * Q_{COORD})] * P_P$

$= [1-(1- P_{PGM}) * (1 – P_{COORD})]* P_P$

$= [1-(1- P_{COORD} – P_{PGM} + P_{PGM}*P_{COORD})]* P_P$

$= (P_{COORD} + P_{PGM} - P_{PGM}*P_{COORD})* P_P$

## 5.3 Stadium Subsystem

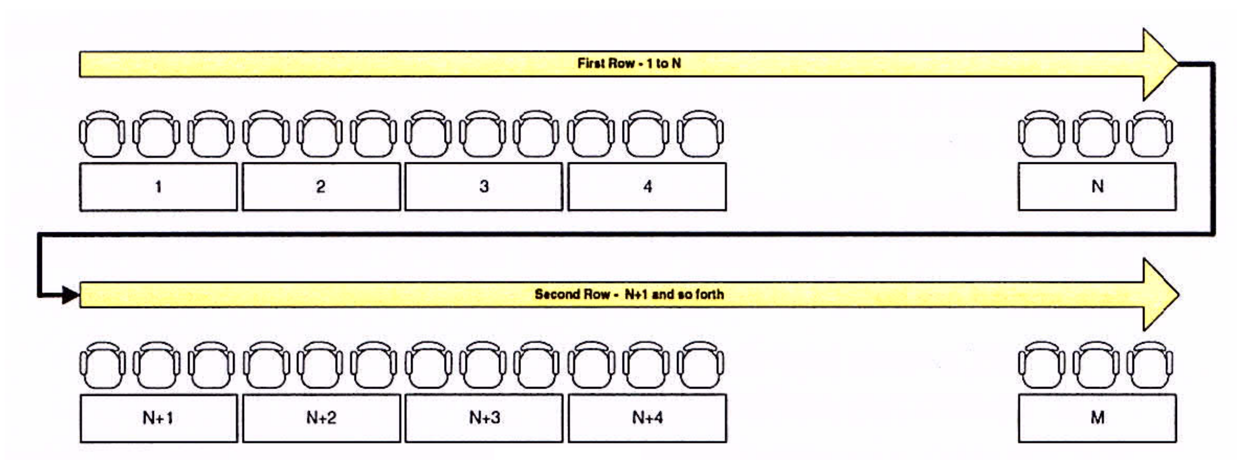
### 5.3.1 Commentary Positions

Commentary positions are a set of tables and three chairs each furnished with, for the relevance of this study mainly a commentary unit located in such a way that it offers the best view of the pitch. Other equipment furnishing a commentary position include

- two headsets
- a telephone set
- power outlets
- two Television Sets that provide information about the players
- a camera delivering a picture to the commentators

The commentary positions are situated in the best possible position in the stadium so that the commentators following the match can have the best view of the match since most of the commentators announce the matches live to home spectators who view and listen to the live images simultaneously. Therefore commentators need to have the same vision that home viewers have and for this reason the commentary positions are as close to the main camera that provides the live match coverage as possible.

The Commentary position is the input port of the audio signal, its arrangement is as shown below




Pitch

**FIGURE 7: Arrangement of commentary units where the commentators' seat**

There are ten CCUs that serve a single CU unit whose performances are independent of each other (Parallel arrangement). Hence:

Suppose

$q_{cu}$ is the probability of failure of a single commentary unit, and

$p_{cu}$ is the probability of success of a single commentary unit, then

the Reliability $R_{cu}$ of a set of 10 commentary units serving a single CCU is obtained as follows

$$q_{set} = q_{cu}^{10}$$

$$R_{cu} = 1 - q_{set}$$

$$= 1 - q_{cu}^{10}$$

$$= 1 - (1-p_{cu})^{10}$$

### 5.3.2 The Commentary Control Room (CCR)

The Commentary Control Room is the main operations centre for all commentary services where all commentary facilities are handled. It is located as close as possible to the Commentary positions for ease of access and houses the following equipment necessary for the propagation of the audio feed:

- CCUs which handle all the audio feeds to and from the Commentary Units
- Matrix breakout boxes that are connected to the Commentary Matrix located at the TOC through fibre optic cables
- Computers
- Tools used for first degree maintenance of the equipment under use
- Clocks
- Telephones

### 5.3.3 Layout and Equipment

Two typical Commentary Control Room layouts are shown in the figures below:

Layout 1

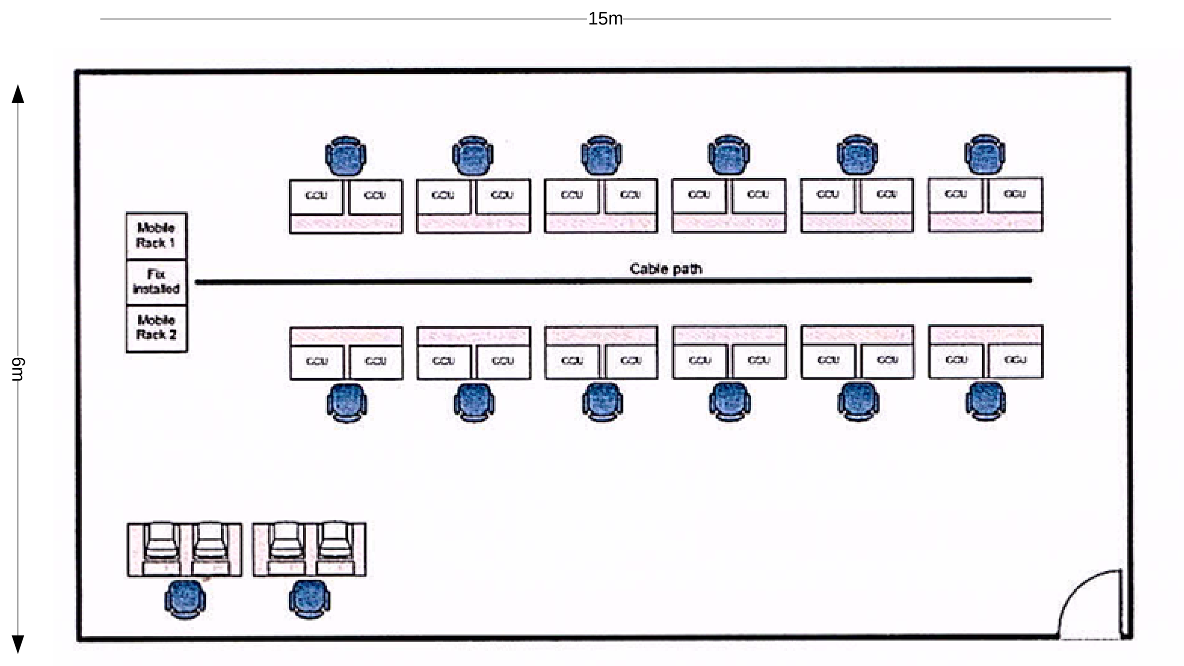



**FIGURE 8: CCR layout 1**

Layout 2

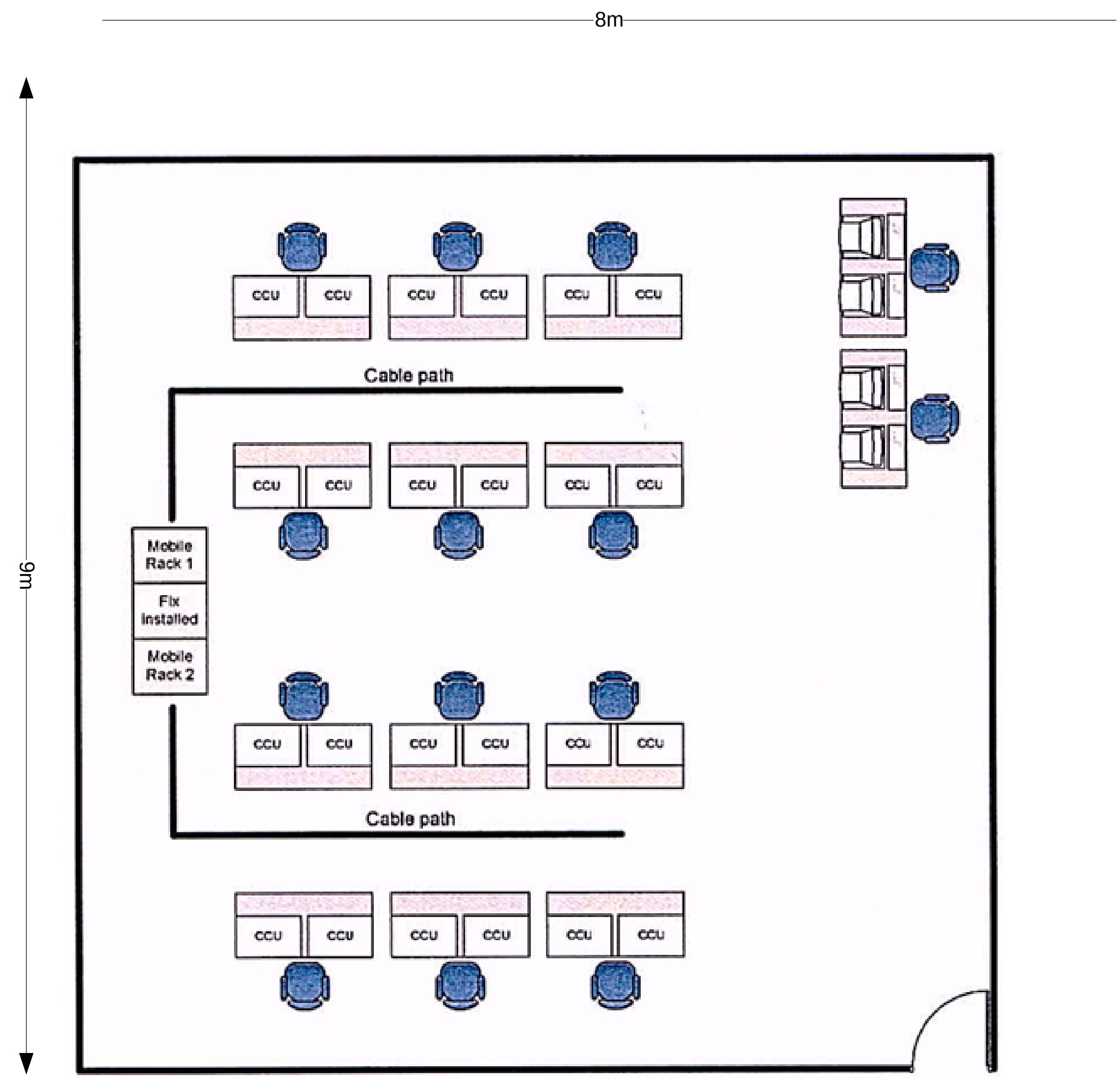



**FIGURE 9: CCR layout 2**

At each table in the CCR, there is

- a Person who is the CCU Operator
- two CCUs that are arranged in parallel
- a power source for the two CCUs

The diagram below shows the arrangement of these objects with each assigned Reliability,

$R_P$ -The Reliability Value of the person operating the Commentary Control Unit with probability $P_p$

$R_{CCU}$ – The Reliability Value of a parallel Configuration of Commentary Control Units with probability

$P_{ccu}$

$R_V$ - The Reliability Value assigned to the Power Source with probability $P_v$

$Q_{CCU}$ – failure probability of a CCU where

$Q_{CCU} = 1 - P_{ccu}$

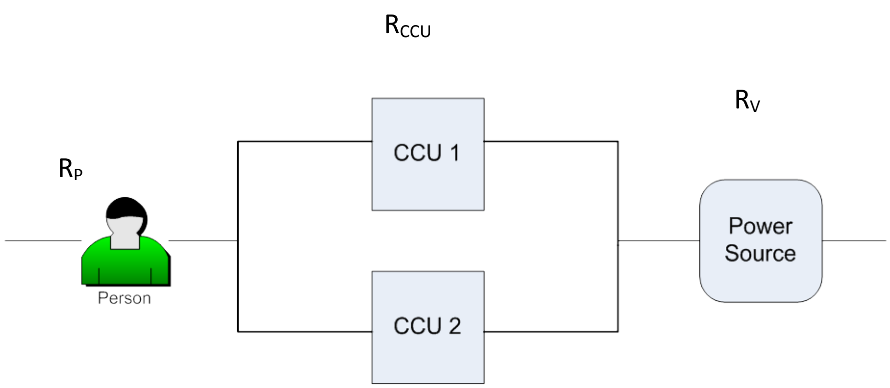



**FIGURE 10: CCU configuration model**

The total Reliability of the above configuration is as follows:

$R_E = P_P *(1-Q_{CCU}{}^2)* P_P$

$= P_P *(1 – (1 - P_{CCU})^2 * P_P$

$R_E = P_P * (2P_{CCU} - P_{CCU}{}^2) * P_P$

Where $R_{CCU} = P_{CCU} + P_{CCU} – P_{CCU} * P_{CCU}$

$= 2P_{CCU} - P_{CCU}{}^2$

(*Parallel configuration of the two CCUs'*)

The configuration in figure 7 is placed in two different layouts shown in figure 8 and figure 9.

For the sake of the reliability formulation a series Reliability Quantification of the Figure 9 Layout is shown below

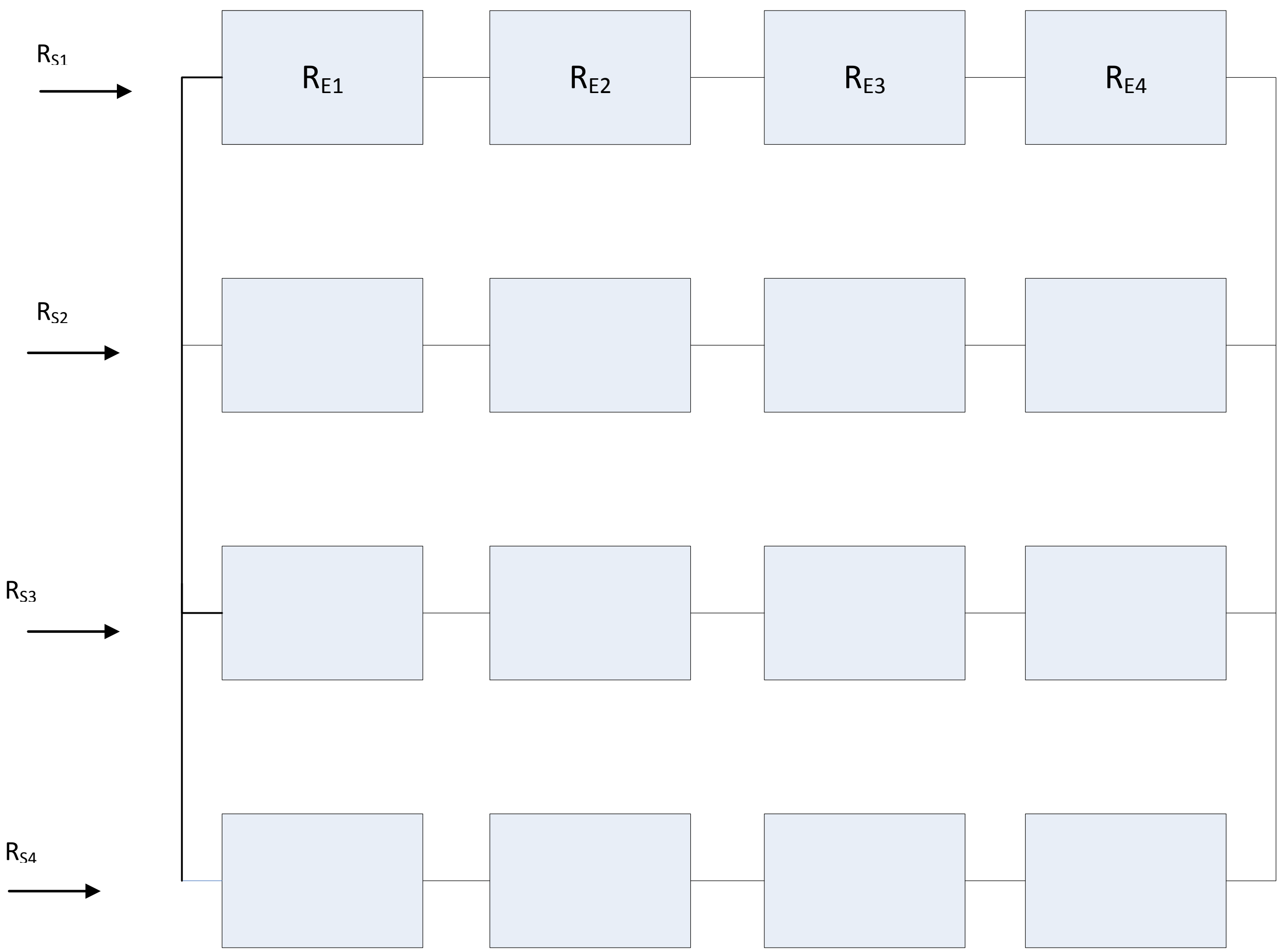



**FIGURE 11: commentary control room layout 1 configuration**

Since all the arrangements and components are the same as in Fig 5

$R_E = R_{E1} = R_{E2} = R_{E3} = R_{E4}$

Therefore the Series Reliability of the first node, $R_{S1}$ is calculated as:

$R_{S1} = P(R_{E1}) \cap P(R_{E2}) \cap P(R_{E3}) \cap P(R_{E4})$

$R_{S1} = R_{E1} * R_{E2} * R_{E3} * R_{E4}$

Therefore

$R_{S1} = R_E^4$

$R_{s1}$ $R_{s2}$ $R_{s3}$ $Rs_4$ are all in parallel and given that they are made up of the same components in the same series configuration as in $R_{s1,}$ then

$R_{s1}=R_{s2} = R_{s3} = R_{s4}= \mathbf{R_E^4}$

Therefore the Reliability of Layout 1 is

$R_{L1} = R_{s1} + R_{s2} + R_{s3} + Rs_4 - R_{s1} * R_{s2} * R_{s3} * Rs_4$

$= \mathbf{4\ R_E^4 - R_E^{16}}$

For the Layout 2

$R_{E1}$ $R_{E2}$ $R_{E3}$ $R_{E4}$ $R_{E5}$ $R_{E6}$

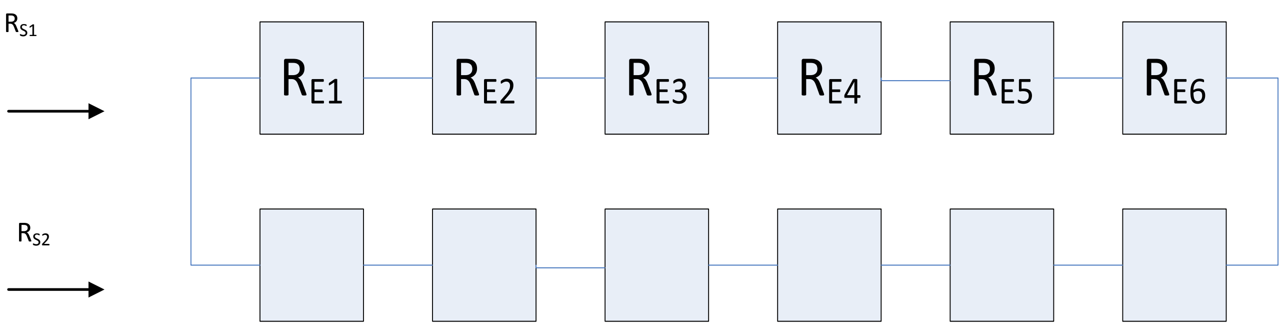



**FIGURE 12: commentary control room layout 2 configurations**

Since all the arrangements and components are the same as in Figure 8

$R_E = R_{E1} = R_{E2} = R_{E3} = R_{E4} = R_{E5} = R_{E6}$

Therefore the Series Reliability of the first node, $R_{S1}$ is calculated as:

$R_{S1} = P(R_{E1}) \cap P(R_{E2}) \cap P(R_{E3}) \cap P(R_{E4}) \cap P(R_{E5}) \cap P(R_{E6})$

$R_{S1} = R_{E1} * R_{E2} * R_{E3} * R_{E4} * R_{E5} * R_{E6}$

Therefore

$R_{S1} = \mathbf{R_E^6}$

$R_{s1}$ $R_{s2}$ are in parallel and given that they are made up of the same components in the same series configuration as in $R_{s1}$, then

$R_{s1} = R_{s2} = \mathbf{R_E^6}$

Therefore Reliability of Layout 2 is

$R_{L2} = R_{s1} + R_{s2} - R_{s1} * R_{s2}$

$= \mathbf{2R_E^6 - R_E^{12}}$

## 5.4 Broadcast Compound

The Broadcast Compound is the area at the stadium venue that houses technical facilities required for broadcasting and the sending of signal feeds to the IBC. These are mainly the TOC and the OB vans for independent broadcasters.

OB vans are mobile television units used by independent broadcasters to do their own production and editing before sending signals to their home countries. Their functionality and reliability analysis is beyond the scope of this study.

When the signal feed leaves the Commentary Control Room (CCR) it enters the TOC via the Commentary Interface Room (CIR) which is adjacent to the Technical Operations Center. In the CIR there are two racks that receive and distribute the signal feed.

- The Commentary Matrix Rack(CMR) for OB Van inserts and distribution $R_{CMR}$
- Intercom and Trunking Rack(ITR) that has codecs(devices used for encoding/decoding signals) for production related connections $R_{ITR}$

### 5.4.1 Reliability model of Commentary Interface Room $R_{CIR}$

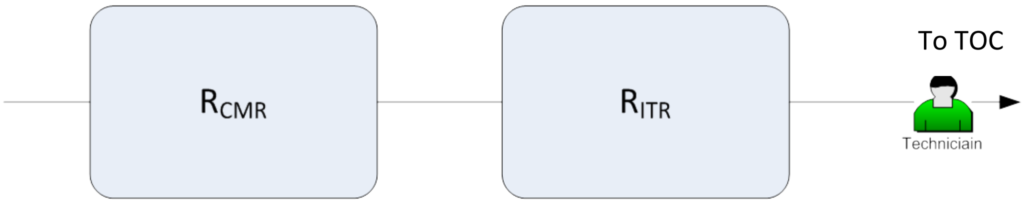



**FIGURE 13: CIR configuration model**

Let

$P_{CMR}$ be the probability of successful operation of the commentary matrix rack

$P_{ITR}$ be the probability of successful operation of the Intercom and Trunking rack

$P_P$ probability that the technician operates the equipment successfully

$\mathbf{R_{CIR}} = P_{CMR} * P_{ITR} * P_P$

### 5.4.2 Reliability Model for the Technical Operations Center

The TOC is the main distribution point and interface between the facilities used to transfer signals. Its key function is to receive the unilateral and multilateral audio and video signals at the venues and to send them to the IBC through the telecommunications structures that have been set, the fibre optic cables, copper cables and via satellite. The TOC is located in portable cabins which receive the audio and video feeds. It contains audio and video feed receivers which are received and sent out simultaneously to the IBC via the Broadcast Compound.

The TOC Reliability Model is shown below:

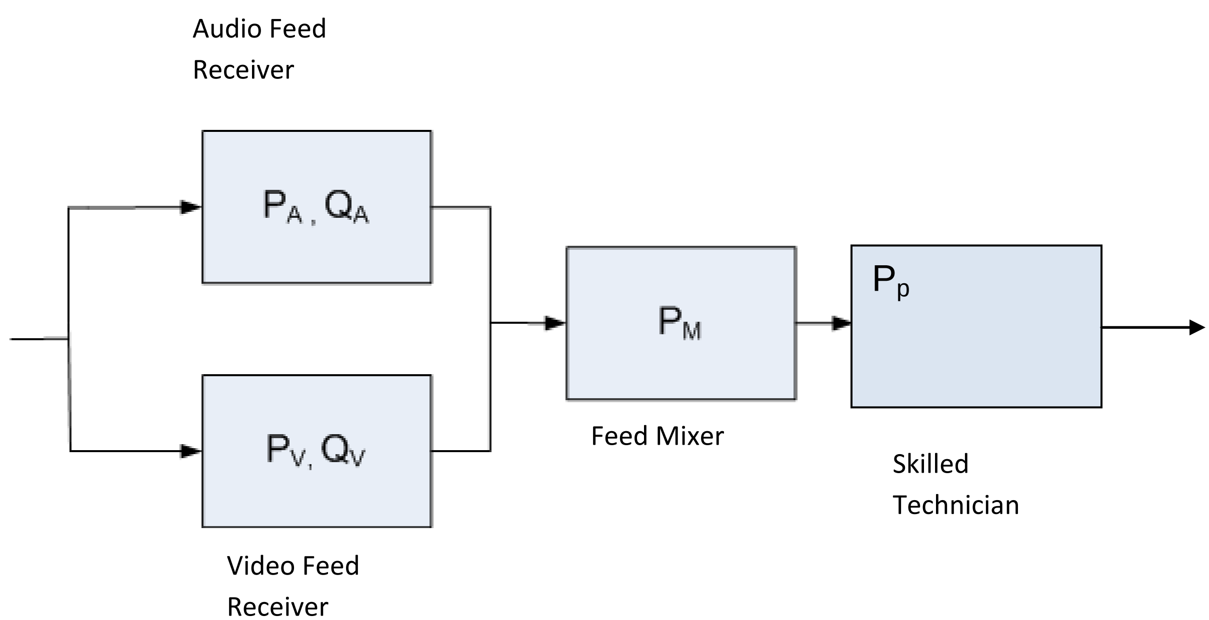



**FIGURE 14: technical operations center configuration model**

Suppose $P_A$ is the probability of successful operation of an audio feed receiver

$Q_A$ is the probability of failure of an audio feed receiver

$P_V$ is the probability of successful operation of a video feed receiver

$Q_V$ is the probability of successful operation of a video feed receiver

$P_p$ is the reliability of the technician

Then

$$\mathbf{R_{TOC}} = (1 - Q_A * Q_V) * P_M * P_p$$

$$= [1 - (1 - P_A)(1 - P_V)] * P_M * P_p$$

$$= (P_V + P_A - P_A P_V) * P_M * P_p$$

Where $Q_A = 1 - P_A$ and $Q_V = 1 - P_V$

## 5.5 The International Broadcast Centre (IBC) System

The international Broadcast Center is the Central hub of all football broadcasting operations done and sent to the different viewers worldwide. For the purposes of this study the operations of the IBC's Master Control Room (MCR) and Commentary Switching Centre (CSC) are of interest

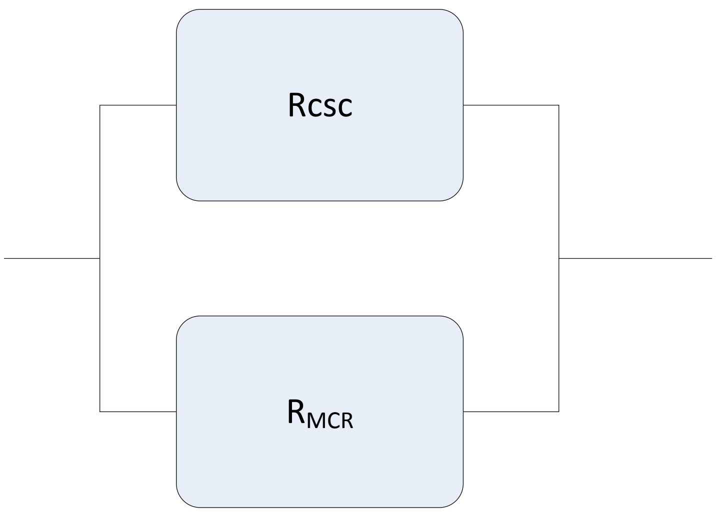



**FIGURE 15: The configuration of the MCR and CSC at the *IBC***

$\mathbf{R_{IBC}} = R_{CSC} + R_{MCR} - R_{CSC} * R_{MCR}$

### 5.5.1 The Master Control Room

The Master Control Room is the central distribution point at the IBC for all the incoming and outgoing video and audio feeds that are captured at the stadium venues. All incoming feeds from either fibre optic or satellite downlinks are monitored and distributed to satellite farms and other telecom interfaces, its Reliability will be denoted by $R_{MCR.}$

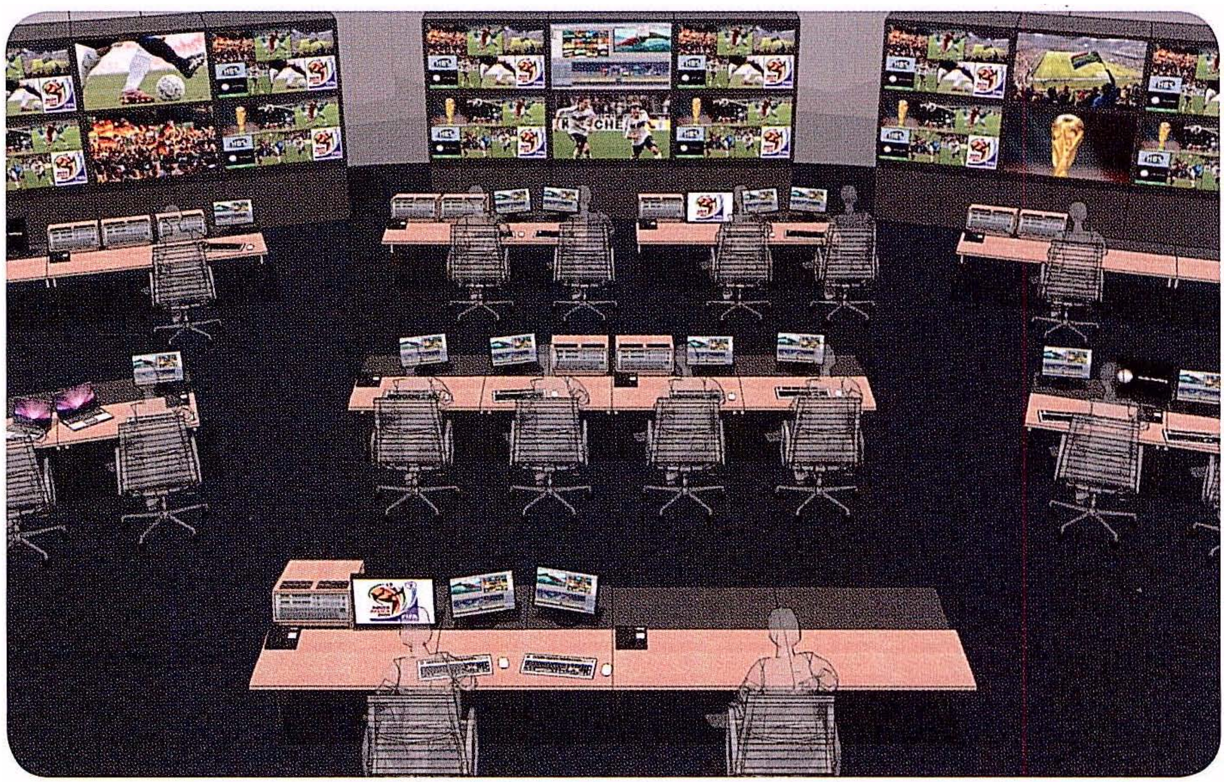


Figure 16: A 3D rendering of the Master Control Room (*Adapted from the HBS staff book*)

In the MCR incoming feeds are separated and grouped into multilateral and unilateral feeds according to bookings made by broadcasters influencing the setup and layout of the different need categories.

A multilateral feed is a feed produced for the collective benefit of a group of broadcasters. A unilateral feed is produced by an individual broadcaster for the individual use of a given broadcaster

### 5.5.2 Multilateral Production Reliability Model

The signal feed coming in from the stadia goes into the frame synchronizer where distinctive bit sequences are identified, *i.e.*, distinguished from data bits thereby permitting those data bits within a frame to be extracted for decoding or retransmission. From the frame synchronizer the signal feeds are down converted then sent into the Production Center.

Since all these are essential digitalized processes their reliabilities are taken to be in series and denoted as $R_{DS}$ for the Digital frame synchronizer (DCS) and $R_{DC}$ for the Down Conversion (DC) in the figure below.

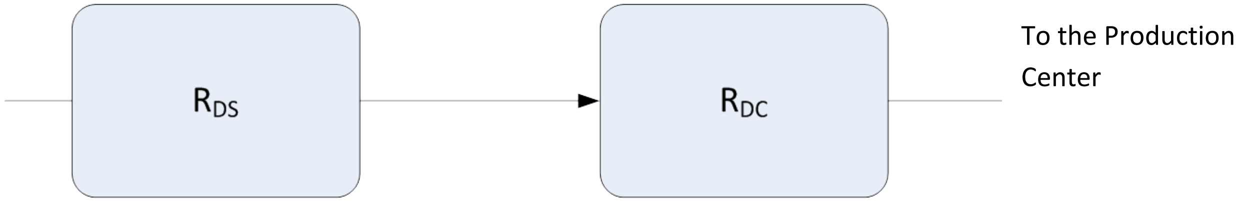



**FIGURE 17: configuration model of the digital synchronizer and down converter**

In the Production Centre a number of processes occur that are largely dependent on human reliability factors and they occur simultaneously. The Processes are shown as follows

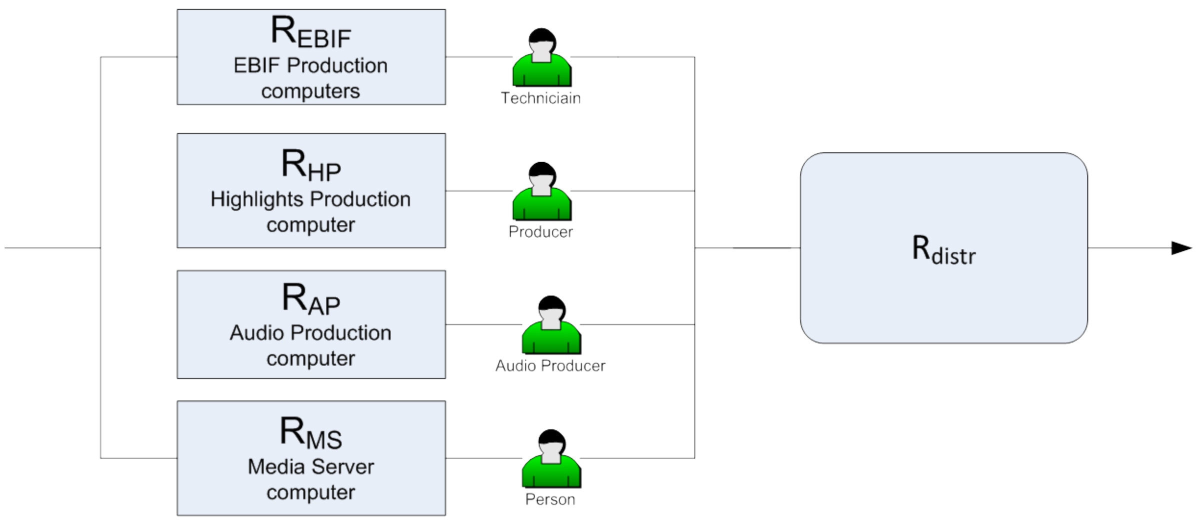



**FIGURE 18: Configuration Model of the production center**

Let

$Q_{EBIF}$ be the probability of failure of the Extended Broadcast International Feed (EBIF) production computers

$Q_{HP}$ be the probability of failure of the highlights feed computers

$Q_{AP}$ be the probability of failure of the audio production computer

$Q_{MS}$ probability of failure of the media server computers

$P_{EBIF}$ probability of success of the EBIF production computers

$P_{HP}$ probability of success of the Highlights production computers

$P_{AP}$ probability of success of the audio production computers

$P_{MS}$ probability of success of the media server room

$P_{DS}$ Probability of success of the digital synchronizer

$P_{DC}$ probability of success of the down conversion

$P_{distr}$ probability of successful operation of the distributor

$$R_{MULTI} = P_{DS} * P_{DC} *[1-(Q_{EBIF} * Q_{HP} * Q_{AP} * Q_{MS})] * P_{distr}$$

$$= P_{DS} * P_{DC} *[1-((1-P_{EBIF}) * (1-P_{HP}) * (1-P_{AP}) * (1-P_{MS}))] * P_{distr}$$

$$= P_{DS} * P_{DC} * P_{distr} [1 – (1- P_{HP} – P_{EBIF} + P_{EBIF}P_{HP}-P_{AP} + P_{AP}*P_{HP} + P_{AP}*P_{EBIF} –P_{AP}*P_{EBIF}*P_{HP} – P_{MS}+ P_{MS}*P_{HP}+P_{MS}*P_{EBIF}-P_{MS}*P_{EBIF}*P_{HP}+P_{MS}*P_{AP} – P_{MS}*P_{AP}*P_{HP} – P_{MS}*P_{AP}*P_{EBIF} + P_{MS}*P_{AP}*P_{EBIF}*P_{AP})]$$

$$\mathbf{= P_{DS}* P_{DC}* P_{distr}* (P_{HP} + P_{EBIF} – P_{EBIF}*P_{HP} + P_{AP} - P_{AP}*P_{HP} - P_{AP}*P_{EBIF} + P_{AP}*P_{EBIF}*P_{HP} + P_{MS} - P_{MS}*P_{HP} - P_{MS}*P_{EBIF} + P_{MS}*P_{EBIF}*P_{HP} - P_{MS}*P_{AP} + P_{MS}*P_{AP}*P_{HP} + P_{MS}*P_{AP}*P_{EBIF} - P_{MS}*P_{AP}*P_{EBIF}*P_{AP})}$$

From the Production Centre the signal feeds are sent for distribution to the various destinations worldwide through the satellite farms $R_{distr.}$

(Equations)

### 5.5.3 Unilateral feed Reliability Model

Unilateral signal feeds coming in from the stadiums go into a UNI-Router where they are processed into selected paths in the network for specific broadcasters. This is usually for the larger broadcasters who would have requested special arrangements and have broadcast facilities at the IBC. From the UNI-Router the signal feeds go to the broadcaster facilities in the IBC before being sent to their home countries.

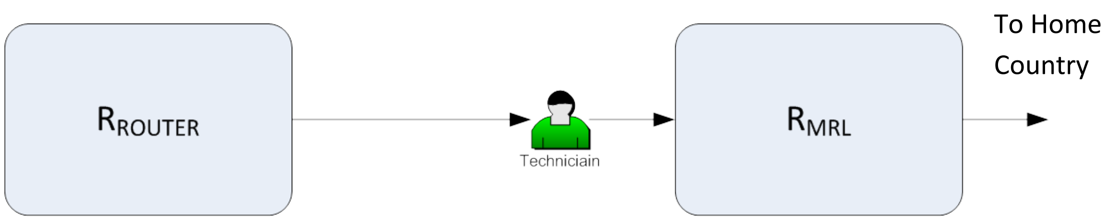



**FIGURE 19: Configuration model of the unilateral feed**

Let

$P_{ROUTER}$ be the probability of successful operation of the router

$P_{MRL}$ probability of successful operations of the individual broadcaster

$P_P$ probability of successful operation by technician

$R_{UNI} = P_{ROUTER} * P_{MRL} * P_p$

The MCR Reliability can therefore be summarized in the Reliability block diagram below as

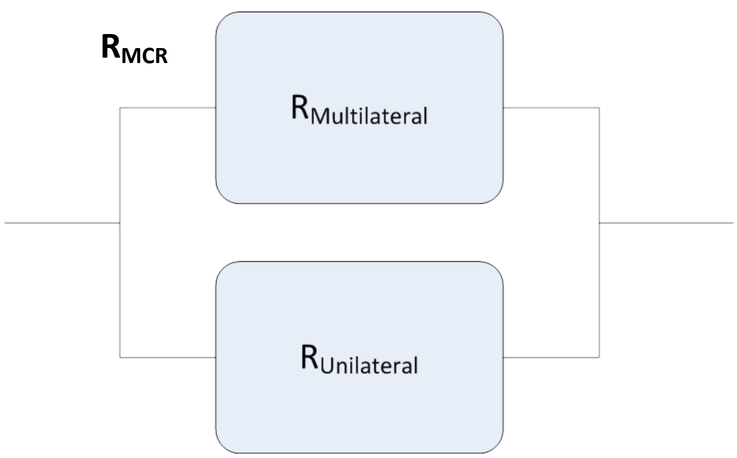



**FIGURE 20: Master Control Room configuration with respect to multilateral and unilateral feeds**

$\mathbf{R_{MCR}} = R_{MULTI} + R_{UNI} - R_{MULTI} * R_{UNI}$

## 5.6 Commentary Switching Centre

The commentary switching Centre controls and patches all the commentary circuits coming in from stadia into the IBC and beyond. Computer based audio circuit switching is used, comprised of a matrix switcher, a switch connecting multiple inputs of the commentary signal to multiple outputs, ISDN Turnaround Panels used to simultaneously transmit the audio signals, off tube commentary units and demarcation panels.

The Reliability Block Diagram of the Commentary Switching Centre is shown below.

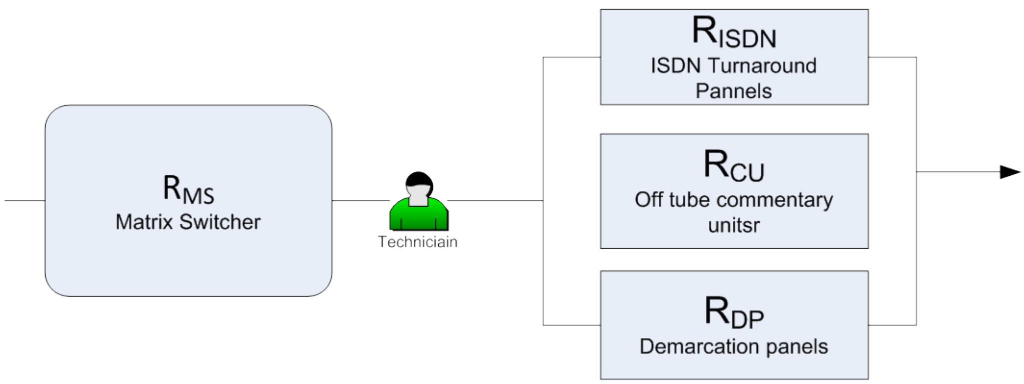



**FIGURE 21: Commentary Switching Centre configuration model**

Let

$Q_{ISDN}$ be the probability of failure of the turnaround panels

$Q_{CU}$ probability of failure of the offtube commentary units

$Q_{DP}$ probability of failure of the demarcation panels

$P_{ISDN}$ probability of success of the ISDN panels

$P_{CU}$ probability of success of the offtube commentary units

$P_{DP}$ probability of success of demarcation panels

$P_{MS}$ probability of success of the matrix switcher

$P_P$ reliability of the technician

**$R_{CSC}$** $= [1-(Q_{ISDN} * Q_{CU} * Q_{DP})] * P_{MS} * P_P$

$= [1-(1 – P_{ISDN})*(1 – P_{CU})*(1-P_{DP})] *P_{MS} * P_P$

$= [1-(1 - P_{CU} – P_{ISDN} + P_{ISDN}*P_{CU} – P_{DP} + P_{CU}*P_{DP} + P_{ISDN}*P_{DP} – P_{ISDN} * P_{CU}*P_{DP})]* P_{MS} * P_p$

**$= (P_{CU} + P_{ISDN} + P_{DP} - P_{ISDN}*P_{CU} - P_{CU}*P_{DP} - P_{ISDN}*P_{DP} + P_{ISDN}*P_{CU}*P_{DP}) * P_{MS} * P_p$**

# 6. Reliability Allocation and Analysis

## 6.1 Introduction

The simplest way to allocate reliabilities is to uniformly distribute reliabilities among all components. This manner of allocation though not the best, is easy to use and allows costs to be taken into account of improving the reliability of different subsystems and components.

When dealing with reliability, improvement and optimization opportunities fall into either one of two options:

- Fault Avoidance which is achieved by using high-quality and high-reliability components.
- Fault Tolerance which is achieved by redundancy of the system as well as a layout overhaul.

A reliability assessment of each subsystem of the CS will be made, reliability values assigned and quantified and finally an assessment done to see if the system goals are being met in terms of the reliability benchmarks set.

## 6.2 Reliability Benchmark

According to Moulding (2010) "There is still work to be done to ensure 'the fine-nines' reliability needed to get consistency is achieved". In his statement above, Moulding refers to a failure rate of one in a hundred thousand runs of broadcast equipment and infers that a reliability of approximately 0.99999 is sufficient to achieve consistency in broadcast system operations.

## 6.3 System Reliability

As can be seen in table 9 in the appendix, the highest system reliability modeled is 0.99989500 rounded off to 0.9999 and interpreted as**: For every ten thousand runs of the system, the commentary system will suffer a fault once.**

Ideally broadcasters consistently demand a 100% reliability of live broadcasts ensured through built-in redundancies by way of the satellite feed in the commentary system and backup equipment. The diagram below shows the signal flow in the redundant satellite path.

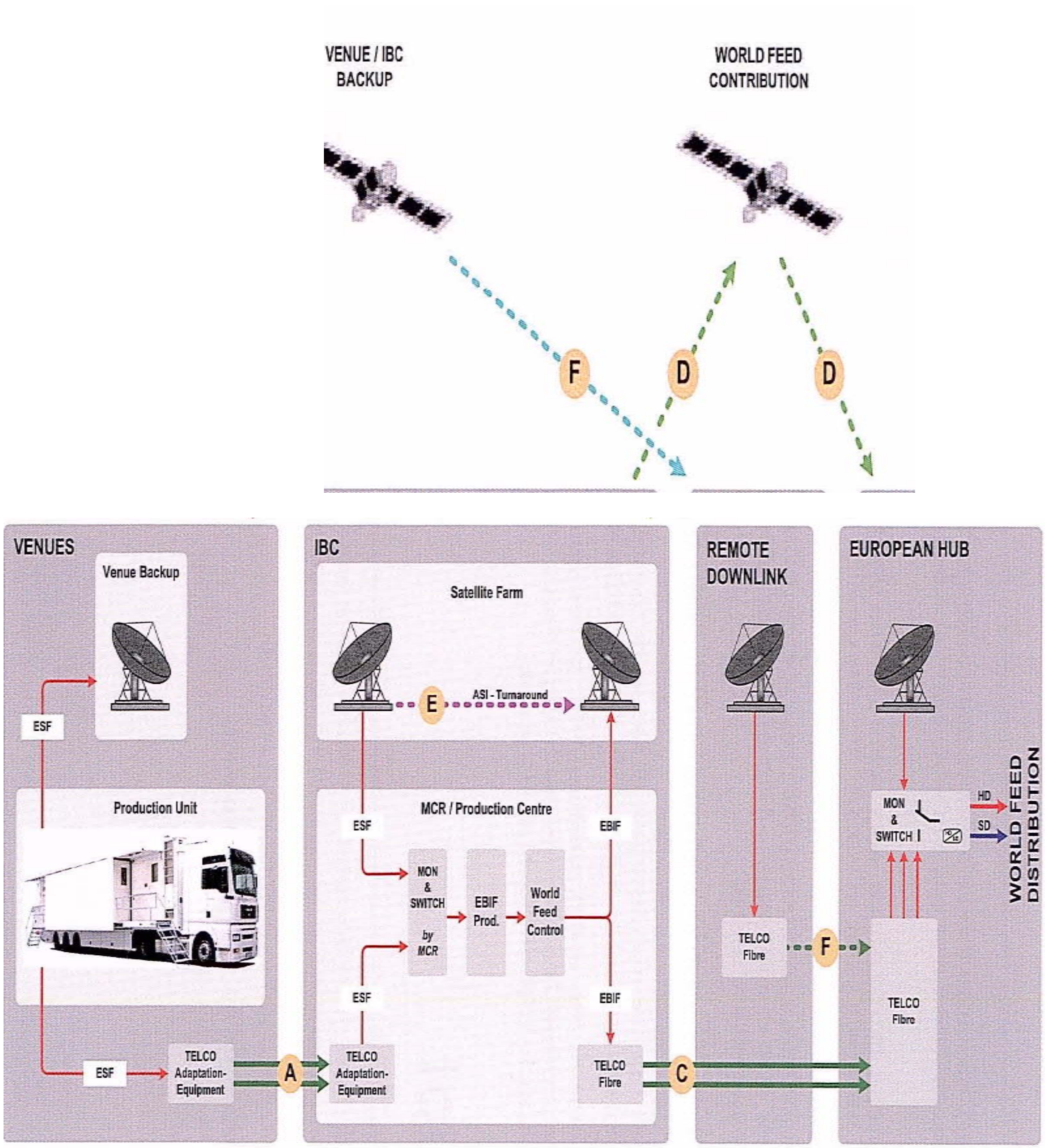



**Figure 22: Diagram showing the redundant satellite feed used to propagate the signal feed** (*adapted from the HBS staff book*)

The satellite path only comes into play in cases of technical necessity when problems are experienced in the fibre cable connectivity, it is thus always on standby.

The greatest bottleneck showing a low reliability value is the stadium venue subsystem. The stadium subsystem where the signal emanates is prone to many faults due to its complexity and dependence on human interfaces. The human reliability aspect has been discussed in section 5.1.

The redundancy built into the stadium subsystem involves the PGM and COORD wires that propagate the signal feed using either copper or fibre cables. The cable redundancy diagram is shown below:

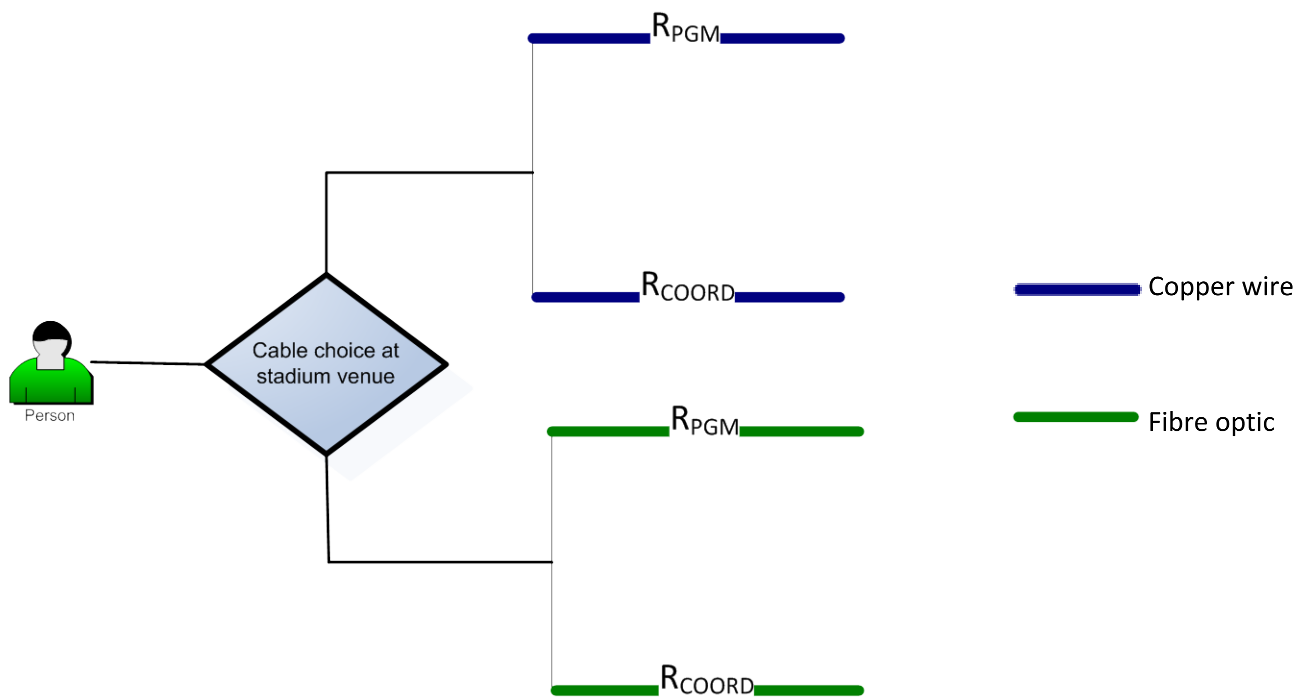



**Figure 23: Redundancy of the PGM and COORD wires of the stadium subsystem.**

In addition to the redundant wire paths at the stadium venue, backup equipment is also available to immediately replace any defective equipment. The CCR houses backup CU, CCU and cable equipment and all through the stadium venue back up cameramen, audio technicians and other technical personnel are constantly on standby. This creates a redundancy whose effect on the overall reliability of the wires is shown in table 2 in the appendix. Individually the copper and fibre wires have a lower reliability but once the redundancy is considered the wires reliability is improved and quantified as the PGM and COORD wires reliability.

### 6.3.1 The Stadium Subsystem

The CCR

There are two different layouts to the CCR with different space requirements that influence the reliability of the commentary system. During the World Cup the two layouts were used in

Bloemfontein and at the Loftus stadium in Pretoria. The room measurement sizes are shown in figures 8 and figure 9 in section 5.3.3.

Stadium managers' charge broadcasters per room specification and the cost allocation used is against the room area (in Rand per square metre, R/ $m^2$). The order of magnitude estimates of the room sizes are shown in figure 8 and figure 9.

Assuming the rental cost of the CCR is R300/ $m^2$ **for the duration of the world cup** then for the two layouts, the rental cost comparison is shown below

| | **Area** | **Cost/m2** | **Layout Cost** |
|---|---|---|---|
| **Layout 1** | 72 | R 300.00 | R 21,600.00 |
| **Layout 2** | 90 | R 300.00 | R 27,000.00 |

Layout 2 takes up more space and is therefore more costly.

A Reliability comparison is made between the two layouts shown in figures 3 and 4 below

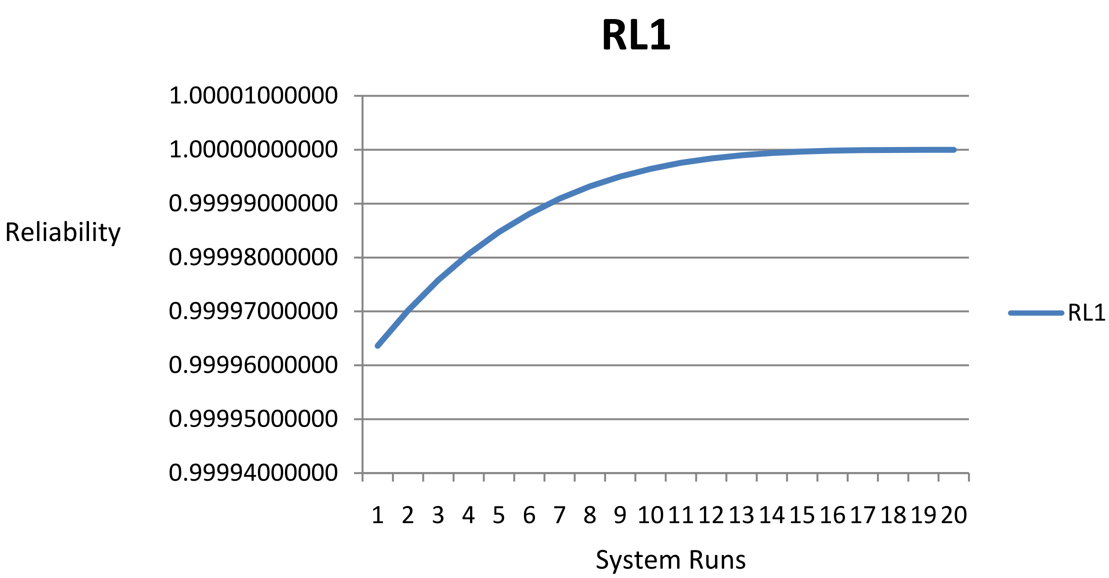



**Figure 24: Reliability chart for CCR layout 1**

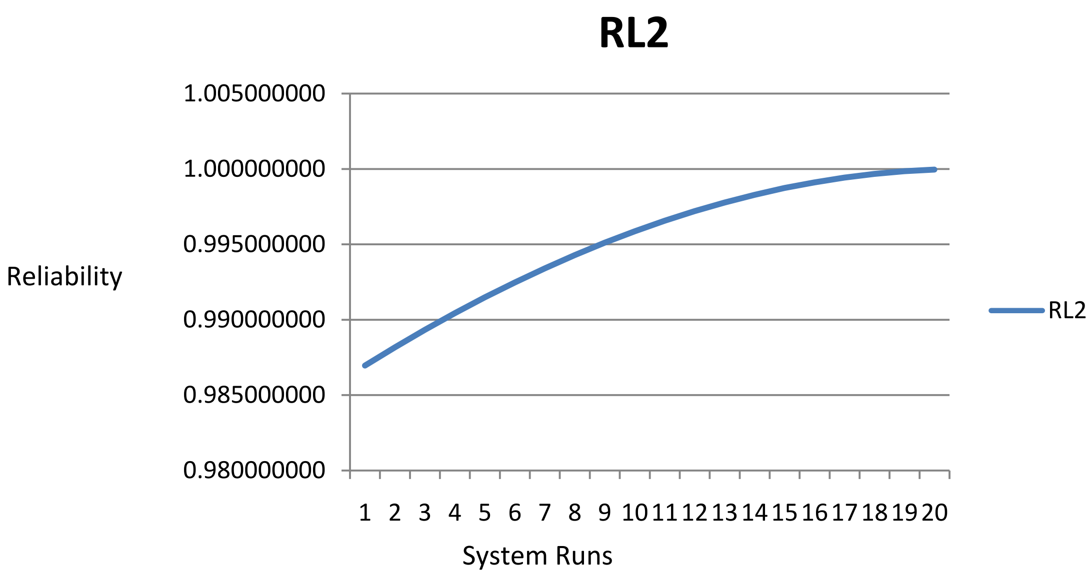



**Figure 25: Reliability chart for the CCR layout 2**

The diagrams above show that layout 1 has a larger reliability value than layout 2, reflecting a more reliable arrangement of CCR components in layout 1. This can be attributed to more parallel nodes of CCUs that reduce the likelihood of failure since nodes are mutually independent. The total area used for each layout is:

Layout 1 - (8m x 9m) 72m$^2$

Layout 2 – (15m x 6m) 90m$^2$

Layout 1 gives a better reliability value, uses up less space, in turn making it cheaper than layout 2.

Layout 2 is also without its advantages:

7 There are approximately 12 cables that go into a single CCU. Therefore cable arrangements have to be put into perspective for the design and layout of a CCR. Layout 2 provides an easier cable arrangement than layout 1

8 Layout 2 is more spacious and therefore safer since it reduces the likelihood of technicians tripping over cables

**Figure 26: Cabling for CCR layout 2**

Commentary Interface Room

The CIR has a simple layout that is on a set-and-forget connection as the racks act as interfaces to the incoming and outgoing signals. The reliability is shown in Table 3 in the appendix.

### 6.3.2 Technical Operations Area

In the TOC where audio and video feeds are mixed technical issues are rife that influence reliability and quality of the outgoing signal. When asked about the technical issues they face on a day- to day basis technicians working in the TOC had a bunch of problems alike.

The most common problems are

- lip- sync errors
- maintaining the continuity of audio signal formats that come in either the 5.1 audio format or the stereo audio
- excessively variable loudness levels

These recurrent audio issues were a part of the system error tolerance levels which acts as a function of the quality of the audio signal produced.

Using reliability fault avoidance, the three problems stated above can be convincingly contained using highly practical new technologies that are readily deployable into the Commentary System. The three problems are detailed below:

Lip Sync Errors

Lip sync problems are rooted in the different processing times required for audio and video content. With High Definition (HD) content used at the world cup, the problem was more severe. Though video equipment is designed to manage the different video and audio delays, lip- sync problems arise as signals pass through various propagation equipment made by different vendors.

It is therefore difficult to trace the source of lip-sync errors during live transmission as was evidenced by the South African Broadcasting Corporation(SABC) on numerous occasions during the world cup where viewers observed the commentator shouting 'GOOAALL!!' before the goal scorer had scored the goal.

The technology used to solve this problem is digital fingerprinting where lip-sync problems can be identified, measured and traced back to their originating positions. Digital fingerprinting is based on a comparison between a video from a source perfectly synchronized and an area where the problem may emerge due to processing delays. The TOC is one such area together with the IBC facilities in the MCR and CSC.

The greatest advantage to using digital fingerprinting is that it allows the different content broadcasted to be compared across different video and audio formats that different broadcasters use.

Digital fingerprinting is still however at early stages of roll out, set to be officially launched in 2011.

Maintaining the continuity of 5.1 and stereo audio

Delivering 5.1 and stereo programming simultaneously has traditionally been a problematic area that emanates from ineffective up-mixing (stepping from a 2.0 to 5.1 audio signal) on the audio mixers when moving from a 5.1 audio signal to a 2.0 audio signal which occurred when broadcasters where mixing the 5.1 audio content to the traditional 2.0 audio content. A typical problem was experienced by viewers in fan parks where surround speakers were used but proved largely ineffective.

This type of problem influences the quality of the audio production which therefore degrades the viewing experience. Its solution is a low cost set-and-forget modification to the audio stream at the TOC through the CSC matrix which can be used to effectively mix the 5.1 and 2.0 signals to automatically prevent inconsistent audio.

Excessively variable loudness levels

Loudness variation is a problem experienced between channels and between program segments. A typical example occurs during commercials and promos where the loudness variation is evident. To curb this problem loudness control processors are sold on the market and are used on a set-and-forget mode of loudness with the loudness processor maintaining target loudness without undergoing any technical involvement from technicians.

## 6.4 International Broadcast Centre System

The functionality and importance of the IBC to the overall system objectives require it to be at its optimum best at all times. The Reliability of the IBC in table 9 in the appendix is shown to be high even with lowering of the overall system reliability. This is due to the parallel nature of the audio and video circuits with respect to each other as the video feed is dealt with in the MCR and the audio feed in the CSC. This means that if either the MCR or the CSC ever experienced a fault resulting in the loss of audio or a video signal, there is at least some signal that is sent through. This occurs at times when a video feed is visible on the screen but with no sound or the pictures vanish leaving only the sound.

This is part of the problem that causes lip sync errors which can be mitigated by digital fingerprinting mentioned in the section 6.3.2 above.

### 6.4.1 Master Control Room

The majority of processes that occur in the MCR are automated using highly advanced equipment and technology resulting in high reliabilities. It deals with Multilateral and Unilateral coverage that propagate the video signal simultaneously. This makes their fault occurrences independent of each other thereby increasing the reliability of the MCR.

The Multilateral production shoulders the majority of the processes that occur at the IBC via the production centre where the feeds are processed. Processes that occur in the production centre are all simultaneous and independent of each other resulting in the parallel arrangement of the components which in turn translates to an effective system with a high reliability as shown by the distribution in table 6 in the appendix.

The Unilateral feed configuration is composed of series components whose operational reliability is dependent on the reliability of other constituent series components. Its reliability values are shown in table 7 in the appendix and shown to be slightly lower than that of the Multilateral Feed.

### 6.4.2 Commentary Switching Centre

In the CSC computer based audio switching is used resulting in simultaneous processes through the ISDN Turnaround panels, Off-tube Commentary Units and Demarcation Panels. This results in a parallel arrangement of components whose faults are mutually independent and resulting in a signal path with a high reliability value. CSC reliability values are shown in Table 8 of the appendix.

# 7. Reliability Economics

According to Brown et al (2001) customer complaints are an indicator of low reliability whilst the unwillingness of customers to pay for improvements implies that reliability is satisfactory. The broadcast environment is a highly client valued environment with some of the costs that broadcasters are charged based on the technology in use and performance based rates, a function of the reliability of the system. Sportscasters demand high quality and very good reliability as they pay large amounts of money to ensure the feed is sent through to viewers. Revenue streams coming through pay-TV packages from companies such as Multi-Choice, where viewers paying monthly subscriptions for live television feeds expect a high level of consistency in the quality of the feed received.

Reliability will naturally vary across environments to which the CS is exposed, including penalties. This reduces the ability of broadcast investors to forecast cash flows. A reliability cost function is therefore used to gauge cost as a function of the system reliability. The preferred approach would be to formulate the cost function from actual cost data which can be done from past experience which the author of this project does not have. Supporting literature from Hotwire Magazine (2001) states that there are many cases where a general behaviour model of cost versus system reliability can be generated without actual cost data. It uses reliability values generated to model the costs.

An exponential behaviour of the cost is assumed and the function has the following form:

$$C = e^{(1-f)*(R(i) - Rmin)/(Rmax)}$$

Where

C – is the cost function as a function of the system reliability

f – is the feasibility of improving the reliability

Rmin – the minimum achievable reliability that the reliability can be allowed to take

Rmax – The maximum achievable Reliability of the system

From the reliability data obtained in the appendix a system cost function was obtained using the function shown above. The System Cost chart is shown in fig below:

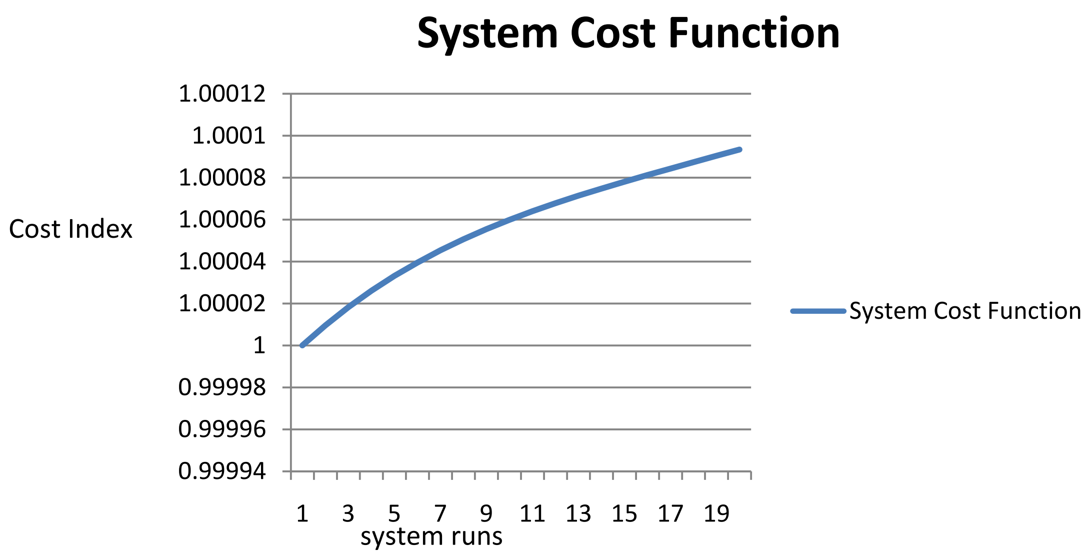



**Figure 27: System Cost function obtained from the Commentary System Reliability Values**

As the reliability increases so does the cost function values as shown in the figure above, indicative of the higher costs of using superior equipment, more labour and the cost of built-in redundancies that ensure the system is consistently at its best. These costs form part of the Cost of Quality Model Shown in the next subsection.

## 7.1 Cost of Quality Model

Preventing, detecting and dealing with defects causes costs that are called ‘quality costs’ that come as a result of the system reliability objectives. Garrison et al. (pp758. 2009)

The Quality Cost Model breaks down costs into four groups: Prevention Costs, Appraisal Costs, Internal Failure Costs and External Failure Costs.

Prevention and Appraisal Costs occur as a result of having back-up equipment, redundancies and using improved technology to prevent any defects in propagating the audio and video signal feeds to viewers.

Internal and External failure costs come about as a result or consequence of the fact ‘no one system built is 100% reliable’ despite the best efforts to prevent any defaults.

The following Quality Cost Report provides an estimate of financial consequences to improved Reliability. It details the prevention, appraisal, internal and external costs that arise from broadcasters’ levels of reliability.

**Broadcast Company**
**Quality Cost Report**
**for duration of World Cup**

| | Amount |
|---|---|
| Prevention Costs: | |
| | R |
| Systems Development | 400,000.00 |
| Quality Training | 500,000.00 |
| Supervision of Prevention Activities | 70,000.00 |
| Reliability Improvement Projects | 1,120,000.00 |
| Total | 2,090,000.00 |
| Appraisal Costs: | |
| Inspection | 600,000.00 |
| Reliability testing | 580,000.00 |
| Supervision of testing and inspection | 300,000.00 |
| Depreciation of test equipment | 200,000.00 |
| Total | 1,680,000.00 |
| Internal Failure Costs: | |
| Net cost of scrap | 400,000.00 |
| Rework labour and overhead | 1,200,000.00 |
| Downtime due to defects in Quality | 170,000.00 |
| Disposal of defective products | 500,000.00 |
| Total | 2,270,000.00 |
| External Failure Costs: | |
| Warranty Repairs | 600,000.00 |
| Warranty Replacements | 200,000.00 |

| | |
|---|---|
| Allowances | 130,000.00 |
| Cost of field servicing | 300,000.00 |
| Total | 1,230,000.00 |
| | |
| Total Quality Cost | 7,270,000.00 |

From the quality cost report shown above most of the costs are traceable to internal costs which can be attributed to the equipment's failure to conform to its designated performance; an example being a defective CU. Most internal costs are detected during the appraisal process where all the commentary equipment to be used is inspected and tested before each match is screened.


**Figure 28: Quality Cost Distribution Pie Chart from the Quality Cost Report**

From the pie chart in figure above a distribution of the cost contributors to the Quality model is shown.

Prevention and Appraisal costs together sum up to 52% indicating that the broadcaster spends more money on mitigating failures and detecting defects in the system through appraisal and prevention activities. An increase in appraisal activity of a broadcaster will lead to more defects being caught before live broadcasts resulting in higher internal costs by way of the cost of scrap, rework and downtime of the defective equipment observed. This positively influences external costs which become less as savings are made in warranty repairs, warranty replacements as well as costs incurred in field servicing. The Pie chart indicates External Failure costs are the lowest owing to the influences of appraisal activities.

Further emphasis on prevention and appraisal may have the effect of reducing the total quality cost as prevention and appraisal costs should be more than offset by a decrease in internal failure costs.

## 8. Conclusion, Facts and Findings

It was decided to conduct this final year project in a world class football environment of the calibre of the Soccer World Cup where the quantity, magnitude and layout of the system components would enable a more detailed and precise reliability viewpoint of broadcast operations pertaining to the commentary system. The first step was to conduct research in order to find reliability methods, tools and techniques that have previously been documented and then find the best practices applicable to this project. A reliability model of all the relevant subsystems of the commentary system was done manually taking into consideration the component layouts and significance to the propagation of audio and video signals.

Actual data relating to subsystem and component reliability was not available but through the guidance of a benchmarked reliability value stated by Moulding (2010) of 0.99999 a reliability assessment was enabled by allocating reliabilities to subsystem components in the commentary system model. A key factor to reliability noted is the layout configuration of the subsystem components. A parallel arrangement of components achieves higher reliability than that of a series arrangement due to mutual independence of those components that are configured in parallel as evidenced by the two CCR layouts which were placed in comparison. The duration of a live football match is approximately two hours and during that time, every effort is made to ensure reliability is high. Redundancies in the commentary system help enable a constant flow of the signal by creating alternate paths through a backup satellite path, alternate PGM and COORD wire routes, backup equipment and technicians. However quality problems are rife that make it a challenge to quantify their influence on reliability. The three most common problems noted; lip sync errors, maintaining the continuity of audio signal formats and excessively variable loudness levels affect the quality of the signal sent to viewers resulting in an unpleasant viewing experience. Whilst they do not affect the ability of the signal path to be successfully propagated through the system, a bad signal received is as good as no signal received. The problems noted are largely due to the technology in use and are dealt with through fault tolerance. However as new technologies are rolled out, such quality problems can be mitigated.

Efforts to ensure high system reliability is achieved result in an increase in overall system costs. A quality cost model was used to emphasize those costs that are reliability centred. Emphasis on prevention and appraisal activities has the effect of reducing the total quality cost as prevention and appraisal costs are offset by a decrease in internal failure costs.

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## Appendix

| $R_{person}$ | $R_{power}$ | $P_{ccu}$ | $R_{table}$ | $R_S$ | $\mathbf{R_{L1}}$ | $R_{S2}$ | $\mathbf{R_{L2}}$ |
|---|---|---|---|---|---|---|---|
| 0.98 | 0.99999 | 0.99998 | 0.97999 | 0.922331 | **0.99996360976** | 0.885789 | **0.986955900** |
| 0.981 | 0.99999 | 0.999981 | 0.98099 | 0.926102 | **0.99997017785** | 0.891226 | **0.988168278** |
| 0.982 | 0.99999 | 0.999982 | 0.98199 | 0.929884 | **0.99997582987** | 0.896691 | **0.989327275** |
| 0.983 | 0.99999 | 0.999983 | 0.98299 | 0.933677 | **0.99998065118** | 0.902184 | **0.990432001** |
| 0.984 | 0.99999 | 0.999984 | 0.98399 | 0.937482 | **0.99998472380** | 0.907705 | **0.991481558** |
| 0.985 | 0.99999 | 0.999985 | 0.98499 | 0.941299 | **0.99998812633** | 0.913253 | **0.992475037** |
| 0.986 | 0.99999 | 0.999986 | 0.98599 | 0.945127 | **0.99999093377** | 0.918831 | **0.993411522** |
| 0.987 | 0.99999 | 0.999987 | 0.98699 | 0.948967 | **0.99999321742** | 0.924436 | **0.994290084** |
| 0.988 | 0.99999 | 0.999988 | 0.98799 | 0.952819 | **0.99999504471** | 0.93007 | **0.995109787** |
| 0.989 | 0.99999 | 0.999989 | 0.98899 | 0.956682 | **0.99999647908** | 0.935732 | **0.995869682** |
| 0.99 | 0.99999 | 0.99999 | 0.98999 | 0.960558 | **0.99999757979** | 0.941424 | **0.996568813** |
| 0.991 | 0.99999 | 0.999991 | 0.99099 | 0.964445 | **0.99999840182** | 0.947144 | **0.997206210** |
| 0.992 | 0.99999 | 0.999992 | 0.99199 | 0.968343 | **0.99999899569** | 0.952893 | **0.997780897** |
| 0.993 | 0.99999 | 0.999993 | 0.99299 | 0.972254 | **0.99999940732** | 0.958671 | **0.998291885** |
| 0.994 | 0.99999 | 0.999994 | 0.99399 | 0.976176 | **0.99999967785** | 0.964478 | **0.998738175** |
| 0.995 | 0.99999 | 0.999995 | 0.99499 | 0.98011 | **0.99999984350** | 0.970314 | **0.999118759** |
| 0.996 | 0.99999 | 0.999996 | 0.99599 | 0.984056 | **0.99999993538** | 0.97618 | **0.999432615** |
| 0.997 | 0.99999 | 0.999997 | 0.99699 | 0.988014 | **0.99999997936** | 0.982076 | **0.999678714** |
| 0.998 | 0.99999 | 0.999998 | 0.99799 | 0.991984 | **0.99999999587** | 0.988001 | **0.999856013** |
| 0.999 | 0.99999 | 0.999999 | 0.99899 | 0.995966 | **0.99999999974** | 0.993955 | **0.999963462** |

**Table 1: Commentary Control Room Reliability Allocations**

| R(person) | P(coord) | P(prog) | R(wires)-copper | R(wires)-fibre | R(wires) |
|---|---|---|---|---|---|
| 0.99 | 0.99998 | 0.99998 | **0.9899999996040000** | **0.9899999996040000** | **0.9998999999920800** |
| 0.99 | 0.999981 | 0.999981 | **0.9899999996426100** | **0.9899999996426100** | **0.9998999999928520** |
| 0.99 | 0.999982 | 0.999982 | **0.9899999996792400** | **0.9899999996792400** | **0.9998999999935850** |
| 0.99 | 0.999983 | 0.999983 | **0.9899999997138900** | **0.9899999997138900** | **0.9998999999942780** |
| 0.99 | 0.999984 | 0.999984 | **0.9899999997465600** | **0.9899999997465600** | **0.9998999999949310** |
| 0.99 | 0.999985 | 0.999985 | **0.9899999997772500** | **0.9899999997772500** | **0.9998999999955450** |
| 0.99 | 0.999986 | 0.999986 | **0.9899999998059600** | **0.9899999998059600** | **0.9998999999961190** |
| 0.99 | 0.999987 | 0.999987 | **0.9899999998326900** | **0.9899999998326900** | **0.9998999999966540** |
| 0.99 | 0.999988 | 0.999988 | **0.9899999998574400** | **0.9899999998574400** | **0.9998999999971490** |
| 0.99 | 0.999989 | 0.999989 | **0.9899999998802100** | **0.9899999998802100** | **0.9998999999976040** |
| 0.99 | 0.99999 | 0.99999 | **0.9899999999010000** | **0.9899999999010000** | **0.9998999999980200** |
| 0.99 | 0.999991 | 0.999991 | **0.9899999999198100** | **0.9899999999198100** | **0.9998999999983960** |
| 0.99 | 0.999992 | 0.999992 | **0.9899999999366400** | **0.9899999999366400** | **0.9998999999987330** |
| 0.99 | 0.999993 | 0.999993 | **0.9899999999514900** | **0.9899999999514900** | **0.9998999999990300** |
| 0.99 | 0.999994 | 0.999994 | **0.9899999999643600** | **0.9899999999643600** | **0.9998999999992870** |
| 0.99 | 0.999995 | 0.999995 | **0.9899999999752500** | **0.9899999999752500** | **0.9998999999995050** |
| 0.99 | 0.999996 | 0.999996 | **0.9899999999841600** | **0.9899999999841600** | **0.9998999999996830** |
| 0.99 | 0.999997 | 0.999997 | **0.9899999999910900** | **0.9899999999910900** | **0.9998999999998220** |
| 0.99 | 0.999998 | 0.999998 | **0.9899999999960400** | **0.9899999999960400** | **0.9998999999999210** |
| 0.99 | 0.999999 | 0.999999 | **0.9899999999990100** | **0.9899999999990100** | **0.9998999999999800** |

**Table 2: Program and Coordination wire Reliability Allocation**

| P(person) | P(CMR) | P(ITR) | **R(CIR)** |
|---|---|---|---|
| 0.99998 | 0.99998 | 0.99998 | **0.99994** |
| 0.999981 | 0.999981 | 0.999981 | **0.999943** |
| 0.999982 | 0.999982 | 0.999982 | **0.999946** |
| 0.999983 | 0.999983 | 0.999983 | **0.999949** |
| 0.999984 | 0.999984 | 0.999984 | **0.999952** |
| 0.999985 | 0.999985 | 0.999985 | **0.999955** |
| 0.999986 | 0.999986 | 0.999986 | **0.999958** |
| 0.999987 | 0.999987 | 0.999987 | **0.999961** |
| 0.999988 | 0.999988 | 0.999988 | **0.999964** |
| 0.999989 | 0.999989 | 0.999989 | **0.999967** |
| 0.99999 | 0.99999 | 0.99999 | **0.99997** |
| 0.999991 | 0.999991 | 0.999991 | **0.999973** |
| 0.999992 | 0.999992 | 0.999992 | **0.999976** |
| 0.999993 | 0.999993 | 0.999993 | **0.999979** |
| 0.999994 | 0.999994 | 0.999994 | **0.999982** |
| 0.999995 | 0.999995 | 0.999995 | **0.999985** |
| 0.999996 | 0.999996 | 0.999996 | **0.999988** |
| 0.999997 | 0.999997 | 0.999997 | **0.999991** |
| 0.999998 | 0.999998 | 0.999998 | **0.999994** |
| 0.999999 | 0.999999 | 0.999999 | **0.999997** |

**Table 3: Commentary Interface Room Reliability Allocation**

| P(person) | P(Video receiver) | P(Audio Receiver) | P(mixer) | R(TOC) |
|---|---|---|---|---|
| 0.99998 | 0.99998 | 0.99998 | 0.99998 | **0.999960000** |
| 0.999981 | 0.999981 | 0.999981 | 0.999981 | **0.999962000** |
| 0.999982 | 0.999982 | 0.999982 | 0.999982 | **0.999964000** |
| 0.999983 | 0.999983 | 0.999983 | 0.999983 | **0.999966000** |
| 0.999984 | 0.999984 | 0.999984 | 0.999984 | **0.999968000** |
| 0.999985 | 0.999985 | 0.999985 | 0.999985 | **0.999970000** |
| 0.999986 | 0.999986 | 0.999986 | 0.999986 | **0.999972000** |
| 0.999987 | 0.999987 | 0.999987 | 0.999987 | **0.999974000** |
| 0.999988 | 0.999988 | 0.999988 | 0.999988 | **0.999976000** |
| 0.999989 | 0.999989 | 0.999989 | 0.999989 | **0.999978000** |
| 0.99999 | 0.99999 | 0.99999 | 0.99999 | **0.999980000** |
| 0.999991 | 0.999991 | 0.999991 | 0.999991 | **0.999982000** |
| 0.999992 | 0.999992 | 0.999992 | 0.999992 | **0.999984000** |
| 0.999993 | 0.999993 | 0.999993 | 0.999993 | **0.999986000** |
| 0.999994 | 0.999994 | 0.999994 | 0.999994 | **0.999988000** |
| 0.999995 | 0.999995 | 0.999995 | 0.999995 | **0.999990000** |
| 0.999996 | 0.999996 | 0.999996 | 0.999996 | **0.999992000** |
| 0.999997 | 0.999997 | 0.999997 | 0.999997 | **0.999994000** |
| 0.999998 | 0.999998 | 0.999998 | 0.999998 | **0.999996000** |
| 0.999999 | 0.999999 | 0.999999 | 0.999999 | **0.999998000** |

**Table 4: Technical Operations Centre Reliability Allocation**

| Stadium Reliability for Layout 1 | Stadium Reliability for Layout 2 |
|---|---|
| 0.999763631 | 0.976988635 |
| 0.999775196 | 0.978193661 |
| 0.999785846 | 0.979345856 |
| 0.999795666 | 0.980444338 |
| 0.999804737 | 0.981488219 |
| 0.999813138 | 0.982476597 |
| 0.999820944 | 0.983408565 |
| 0.999828227 | 0.984283202 |
| 0.999835053 | 0.985099581 |
| 0.999841486 | 0.985856761 |
| 0.999847586 | 0.986553795 |
| 0.999853407 | 0.987189723 |
| 0.999859 | 0.987763577 |
| 0.999864411 | 0.988274376 |
| 0.999869681 | 0.988721131 |
| 0.999874846 | 0.989102843 |
| 0.999879938 | 0.9894185 |
| 0.999884981 | 0.989667081 |
| 0.999889997 | 0.989847555 |
| 0.999895 | 0.989958878 |

**Table 5: Stadium Reliability for the two Commentary Control Room Layouts**

| p(EBIF) | p(HP) | p(AP) | p(MS) | p(DS) | p(DC) | p(DISTR) | **R(MULTI)** |
|---|---|---|---|---|---|---|---|
| 0.99998 | 0.99998 | 0.99998 | 0.99998 | 0.99998 | 0.99998 | 0.99998 | **0.999940001200** |
| 0.999981 | 0.999981 | 0.999981 | 0.999981 | 0.999981 | 0.999981 | 0.999981 | **0.999943001083** |
| 0.999982 | 0.999982 | 0.999982 | 0.999982 | 0.999982 | 0.999982 | 0.999982 | **0.999946000972** |
| 0.999983 | 0.999983 | 0.999983 | 0.999983 | 0.999983 | 0.999983 | 0.999983 | **0.999949000867** |
| 0.999984 | 0.999984 | 0.999984 | 0.999984 | 0.999984 | 0.999984 | 0.999984 | **0.999952000768** |
| 0.999985 | 0.999985 | 0.999985 | 0.999985 | 0.999985 | 0.999985 | 0.999985 | **0.999955000675** |
| 0.999986 | 0.999986 | 0.999986 | 0.999986 | 0.999986 | 0.999986 | 0.999986 | **0.999958000588** |
| 0.999987 | 0.999987 | 0.999987 | 0.999987 | 0.999987 | 0.999987 | 0.999987 | **0.999961000507** |
| 0.999988 | 0.999988 | 0.999988 | 0.999988 | 0.999988 | 0.999988 | 0.999988 | **0.999964000432** |
| 0.999989 | 0.999989 | 0.999989 | 0.999989 | 0.999989 | 0.999989 | 0.999989 | **0.999967000363** |
| 0.99999 | 0.99999 | 0.99999 | 0.99999 | 0.99999 | 0.99999 | 0.99999 | **0.999970000300** |
| 0.999991 | 0.999991 | 0.999991 | 0.999991 | 0.999991 | 0.999991 | 0.999991 | **0.999973000243** |
| 0.999992 | 0.999992 | 0.999992 | 0.999992 | 0.999992 | 0.999992 | 0.999992 | **0.999976000192** |
| 0.999993 | 0.999993 | 0.999993 | 0.999993 | 0.999993 | 0.999993 | 0.999993 | **0.999979000147** |
| 0.999994 | 0.999994 | 0.999994 | 0.999994 | 0.999994 | 0.999994 | 0.999994 | **0.999982000108** |
| 0.999995 | 0.999995 | 0.999995 | 0.999995 | 0.999995 | 0.999995 | 0.999995 | **0.999985000075** |
| 0.999996 | 0.999996 | 0.999996 | 0.999996 | 0.999996 | 0.999996 | 0.999996 | **0.999988000048** |
| 0.999997 | 0.999997 | 0.999997 | 0.999997 | 0.999997 | 0.999997 | 0.999997 | **0.999991000027** |
| 0.999998 | 0.999998 | 0.999998 | 0.999998 | 0.999998 | 0.999998 | 0.999998 | **0.999994000012** |
| 0.999999 | 0.999999 | 0.999999 | 0.999999 | 0.999999 | 0.999999 | 0.999999 | **0.999997000003** |

**Table 6: Multilateral Production Reliability Allocation**

| (MULTI) | p(Router) | p(MRL) | p(Person) | R(UNI) | MCR |
|---|---|---|---|---|---|
| 0.999940001200 | 0.99998 | 0.99998 | 0.99 | 0.98996 | 0.99999940 |
| 0.999943001083 | 0.999981 | 0.999981 | 0.99 | 0.989962 | 0.99999943 |
| 0.999946000972 | 0.999982 | 0.999982 | 0.99 | 0.989964 | 0.99999946 |
| 0.999949000867 | 0.999983 | 0.999983 | 0.99 | 0.989966 | 0.99999949 |
| 0.999952000768 | 0.999984 | 0.999984 | 0.99 | 0.989968 | 0.99999952 |
| 0.999955000675 | 0.999985 | 0.999985 | 0.99 | 0.98997 | 0.99999955 |
| 0.999958000588 | 0.999986 | 0.999986 | 0.99 | 0.989972 | 0.99999958 |
| 0.999961000507 | 0.999987 | 0.999987 | 0.99 | 0.989974 | 0.99999961 |
| 0.999964000432 | 0.999988 | 0.999988 | 0.99 | 0.989976 | 0.99999964 |
| 0.999967000363 | 0.999989 | 0.999989 | 0.99 | 0.989978 | 0.99999967 |
| 0.999970000300 | 0.99999 | 0.99999 | 0.99 | 0.98998 | 0.99999970 |
| 0.999973000243 | 0.999991 | 0.999991 | 0.99 | 0.989982 | 0.99999973 |
| 0.999976000192 | 0.999992 | 0.999992 | 0.99 | 0.989984 | 0.99999976 |
| 0.999979000147 | 0.999993 | 0.999993 | 0.99 | 0.989986 | 0.99999979 |
| 0.999982000108 | 0.999994 | 0.999994 | 0.99 | 0.989988 | 0.99999982 |
| 0.999985000075 | 0.999995 | 0.999995 | 0.99 | 0.98999 | 0.99999985 |
| 0.999988000048 | 0.999996 | 0.999996 | 0.99 | 0.989992 | 0.99999988 |
| 0.999991000027 | 0.999997 | 0.999997 | 0.99 | 0.989994 | 0.99999991 |
| 0.999994000012 | 0.999998 | 0.999998 | 0.99 | 0.989996 | 0.99999994 |
| 0.999997000003 | 0.999999 | 0.999999 | 0.99 | 0.989998 | 0.99999997 |

**Table 7: Unilateral Production Reliability Allocation and Overall Master Control Room Reliability**

| p(Person) | p(ISDN) | p(CU) | p(DP) | p(MS) | R(CSC) |
|---|---|---|---|---|---|
| 0.99 | 0.99998 | 0.99998 | 0.99998 | 0.99998 | 0.98998 |
| 0.99 | 0.999981 | 0.999981 | 0.999981 | 0.999981 | 0.989981 |
| 0.99 | 0.999982 | 0.999982 | 0.999982 | 0.999982 | 0.989982 |
| 0.99 | 0.999983 | 0.999983 | 0.999983 | 0.999983 | 0.989983 |
| 0.99 | 0.999984 | 0.999984 | 0.999984 | 0.999984 | 0.989984 |
| 0.99 | 0.999985 | 0.999985 | 0.999985 | 0.999985 | 0.989985 |
| 0.99 | 0.999986 | 0.999986 | 0.999986 | 0.999986 | 0.989986 |
| 0.99 | 0.999987 | 0.999987 | 0.999987 | 0.999987 | 0.989987 |
| 0.99 | 0.999988 | 0.999988 | 0.999988 | 0.999988 | 0.989988 |
| 0.99 | 0.999989 | 0.999989 | 0.999989 | 0.999989 | 0.989989 |
| 0.99 | 0.99999 | 0.99999 | 0.99999 | 0.99999 | 0.98999 |
| 0.99 | 0.999991 | 0.999991 | 0.999991 | 0.999991 | 0.989991 |
| 0.99 | 0.999992 | 0.999992 | 0.999992 | 0.999992 | 0.989992 |
| 0.99 | 0.999993 | 0.999993 | 0.999993 | 0.999993 | 0.989993 |
| 0.99 | 0.999994 | 0.999994 | 0.999994 | 0.999994 | 0.989994 |
| 0.99 | 0.999995 | 0.999995 | 0.999995 | 0.999995 | 0.989995 |
| 0.99 | 0.999996 | 0.999996 | 0.999996 | 0.999996 | 0.989996 |
| 0.99 | 0.999997 | 0.999997 | 0.999997 | 0.999997 | 0.989997 |
| 0.99 | 0.999998 | 0.999998 | 0.999998 | 0.999998 | 0.989998 |
| 0.99 | 0.999999 | 0.999999 | 0.999999 | 0.999999 | 0.989999 |

**Table 8: Commentary Switching Centre Reliability Allocation**

| R(IBC) | R(system) | System Cost Function |
|---|---|---|
| 0.99999999396443 | 0.99976362 | 1 |
| 0.99999999426790 | 0.99977519 | 1.000011567 |
| 0.99999999457120 | 0.99978584 | 1.000022219 |
| 0.99999999487431 | 0.99979566 | 1.00003204 |
| 0.99999999517724 | 0.99980473 | 1.000041113 |
| 0.99999999548000 | 0.99981313 | 1.000049515 |
| 0.99999999578258 | 0.99982094 | 1.000057323 |
| 0.99999999608498 | 0.99982822 | 1.000064607 |
| 0.99999999638720 | 0.99983505 | 1.000071435 |
| 0.99999999668925 | 0.99984148 | 1.00007787 |
| 0.99999999699111 | 0.99984758 | 1.000083971 |
| 0.99999999729280 | 0.99985340 | 1.000089793 |
| 0.99999999759431 | 0.99985900 | 1.000095388 |
| 0.99999999789565 | 0.99986441 | 1.0001008 |
| 0.99999999819680 | 0.99986968 | 1.000106072 |
| 0.99999999849778 | 0.99987484 | 1.000111238 |
| 0.99999999879858 | 0.99987994 | 1.000116331 |
| 0.99999999909920 | 0.99988498 | 1.000121376 |
| 0.99999999939965 | 0.99989000 | 1.000126393 |
| 0.99999999969991 | 0.99989500 | 1.000131398 |

**Table 9: Calculated Commentary System Reliability along with the System Cost Function and IBC Reliability**