CHAPTER 3

RESEARCH METHODOLOGY

In this chapter the data collection methodology is presented, along with rational behind the choices made. The required data has been collected according to the conceptual reliability study of vapor compression refrigeration system framework presented in previous chapters.

The research methodology adopted contains following steps;

- Identification of data source and data type.
- Data acquisition.
- Analysis of the data for reliability.
- Application of concept of redundancy and revised reliability computation
- Cost analysis.

3.1 DATA ACQUISITION

The collection of authentic data and its analysis was one of the major challenges in this research work. In a non-probabilistic sampling, how big a sample should be is largely a function of the variation in the parameters under study and the precision desired in the study. Sample measure assurance is the procedure of selecting the quantity of refrigerators to be selected in factual examples. The test estimate is a critical element of any factual observational examination where the objective is to make decisions about a great deal from an example. In hone, the example measure utilized in the examination is chosen, in light of the many-sided quantity, trouble and cost in information accumulation, and the need adequate factual essentialness. Therefore a
sample size N=216 refrigerator was selected randomly within the Raebareli city through one service center.

It was a huge task to collect data of refrigerators in such a large number together from different manufacturers. It was also a very typical job to collect their different problems timely. A large number of the sold refrigerators are usually sold in a year’s time and to have full details of the costumers to know the history of the refrigerators was not an easy task. It is also needed to be known, whether they are being serviced for repair and maintenance needs by certified agencies or workshop recommended by the seller or not? It was only possible if the refrigerator selling agency had its own workshop. In the present study the data was obtained through Chandra Sales, a dealer in various domestic refrigeration companies for sale and maintenance having three workshops in the Raebareli city.

From these workshops total, 216 costumes of refrigerators were selected for the last 15 years. They all got repaired for the technical problems which came in these 216 refrigerators in different years during a span of 15 year. To get the data of maintenance of last 15 years was a big challenge.

Analysis of the data was next step. Reliability analysis, employing system dynamic modeling, was carried out using Vensim PLE software.

The life of components of any machine or refrigerating machine is not the same. The life of some component is long and of some components is small. But in this study, for the analysis purposes, the working life of all the components has been assumed to be the same. It has also been assumed that all the components have been designed for 15 years. All the components bear the separate load for their different functioning so the degradation rate of their usefulness is not alike. But in this study, reliability has been
modeled with assumption that in all the components the decay is exponential with the time.

4.1 DATA ANALYSIS

There are several components which are used in domestic refrigerators working on vapor compression system. These components are of much significance and all are equally responsible for the failure. The failure of these shall lead to adversely affect the cooling temperature range and spoil the quality of the stored goods inside the refrigerator. In addition, it is more difficult to access and predict that the system would be successfully working or not. The proper running of the refrigeration cycle depends on continuous and reliable functioning of these components. There is a need for reliability analysis to know their performance evaluation. Generally, it has been observed that system that is more intricate is less unwavering quality of its parts and framework itself. It means that the reliability of an assemblage becomes inversely proportional to its complexity.

About twenty years ago, the improvement in the design of system or component or to improve the factor of safety of system or component, separate sides of their failures were being examined. After getting the results or shortcomings the modification of system or component was possible which is difficult today. The trend of the market is being changed at a very fast speed. Today some of the components being used for refrigeration in VCRS, their new modified version comes in next coming year. During this modification, new techniques are involved. Technicians are busy to examine deeply the reliability from all the sides.
4.1.5 RELIABILITY

It is the capacity of equipment to retain its identity and property over a given span of time under operating conditions.

The Electrical Industrial Association (EIA) the USA states the interpretation of trustiness. According to which,

“Reliability is the probability of an item performing its intended function over a given period of time under the operating conditions encountered.”

By the above-said definition, it is clear that there are four main things in reliability –

- Probability,
- Intended functioning,
- Time and
- Operating conditions.

I. **Probability** - In refrigeration system there are some components that have a very short life and also there are some components which have their life very long. In such condition, if the failure rate is possible to calculate then the average life of the components can be easily known. Suppose to work successfully for a component for one year, the probability rate is 0.90 then it means that if 100 components successfully work for one year then their probability for successful running would be 90.

II. In this research work, 216 domestic refrigerators were taken in the record which was sold 15 years ago in same (Month) time. The coming problems in every year of various components of those refrigerators were recorded. A detailed year wise analysis of the problems of various components of these refrigerators was done. The average performance rate of a particular component was taken in
the year in which that component got a failure. This is the most important factor here by which the performance value of a component is directly indicated [40].

III. It has been already told that a refrigeration system has its four main components as evaporator, compressor, expansion devices and condenser. Now the aim is to measure their separate reliability and also the reliability of their subcomponents. To measure the reliability of all these together, in different chapters their detailed analysis has been done.

IV. Intended Function – There are several components or subcomponents for which some minor failures do not affect the entire system of a refrigeration system or refrigerator. The system works as usual as before. However, there are some important components or subcomponents, if anyone among them fails, then the entire system collapses and working performance becomes worse. The functioning of such components which affects the reliability is called the intended function. Now four main components of a refrigeration system are already intended but only those subcomponents of a component would be called intended which affects the component directly by their performance.

V. Pix Time- The failure rate according to failure records of subcomponents of a component have also been calculated in this research. The period in which machinery or components works successfully without any failure is called pix time. This time may be in anyone either in second, minute, hours, days or years. In this research, the measurement of the successful working time of a component or subcomponent of refrigerator always comes in years.

VI. Successfully working life of a domestic refrigerator is about 15 years. The design considerations are also so adjusted that their machine might be in working in given condition up to 15 years. Generally, it has been seen that the
reliability of any machine decreases with duration of time. Year wise
depreciation rate is determined according to the reliability rate of that machine.
The life of various components is different in domestic refrigerators but in some
important components, their average life has been seen up to 15 years.

VII. Operating Condition – Operating condition depends on the external
atmosphere and working environment. If the operating condition is favorable,
then the machine works successfully up to that time for which its average life
has been prescribed. But if the operating condition is not favorable then the
chances of defect increase in the machine or its components.

VIII. In this research, the refrigerators taken for sampling have got their separate
operating conditions but it has been supposed for reliable measurement that 216
refrigerators selected for sampling are working on the same assumed operating
condition fixed at the time of designing. But in practical situations, the
degradation rate of all the components or subcomponents of those refrigerators
working on designed operating condition would be different. But decay in all
these would be exponentially according to their degradation rate.

3.2.2. FAILURE

If any machine deviates from its working according to its prescribed conditions
then it is considered in failure division. The reliability of a machine or component is
known after observing its failure rate. The failure of a machine depends on three
conditions as given below:

i. When it could not be operated.
ii. Presently it is being operated. But there is a doubt that in future also it could be
operated. Because there is a problem regularly coming in operation of the
machine time to time.

iii. There is any major deterioration continuously being in the machine. With a
duration of the time which is decreasing the reliability of it. So the machine at
any time can be failed. The value of reliability of a machine or system is
considered by its failure rate. If the failure rate is high then the reliability of
machine would go down in the same degree [16, 41].

**Types of Failure** – A well-designed machine in which best R&D and materials are
used and properly tested also have enough failure chances. Generally, these failures are
of three types. (i) Early failure, (ii) Chance failure or Random failure, (iii) Wear out
failure

(i) **Early failure** – If working of a machine or component stops before the
scheduled time then it is called early failure. Early failure occurs when there is
variation in the manufacturing process of machine components or quality control is
improper. It means that the testing of components was not performed according to
norms. This work of testing belongs to production unit which checks the components to
work for a required period. If there is any problem then its necessary modification is
done at the same time. In the same process, the warranty of the machine or system is
also determined.

(ii) **Chance Failure** – There is the probability of chance failure in any working
refrigerating machine or system. Such type of failure can occur at any time in the
system. This failure is not presumed. Such type of failure happens only when in
operating condition initial design goes out from consideration then sudden changes are
there. This is very difficult to know about the occurrence of sudden changes. This is the main reason that the prediction of chance failure is not possible.

Chance failure can also be carried into the measurement by using reliable technique. By inserting duplicate components and adjusting maintenance rate etc. a chance failure can be reduced by using reliability technique.

(iii) Wear out Failure – Such types of failure are called aging out failure also. The reliability of more components exponentially decreases due to wearing. Then the rate of failure increases more when the maintenance of components is not properly done. Thus the degradation rate of components increases and the failure happens frequently.

Such failure can be minimized by preventive maintenance. To adjust this preventive maintenance, we decide its frequency by reliability-based analysis. To increase the reliability of the refrigeration system several such calculations have been done in this research also.

Time failure Curve – Several types of research institutes manufacturers and agencies studied deeply about the above described three types of failures at different manufactured machines. By these studies the result was found that in whole lifetime of a component the chances of early failure are more in first one third of its life and between one third to two third of its life the chances of chance failure is more and after the first two-thirds of its total life the chances of wear out failure is more (Fig 3.1) [42-45].
3.3 SYSTEM DYNAMICS

The study of the nonlinear behavior of a complex system is made by the system dynamics approach. System dynamic approach was developed and started in 1950 by Professor Jay Forrester of M.I.T. In 1960 Forrester and team of his graduate engineers brought system dynamics on computer modeling stage from hand simulation stage [46,47]. A computer based system dynamic modeling software was first developed by Richard Bennett in 1958. The name of this language was SIMPLE. [48, 49].

In 1959, Phyllis, Fox and Alexander Rugh improved and simplified the previously launched 1st version of Dynamo language. The dynamic system means a change in the system with time. In this way, many modeling software were made with different modifications. In this research reliability of domestic refrigerators has been enhanced by computer-based simulation and modeling through system dynamic approach [50, 51].

![Fig 3.1: Types of failure during the whole life of the dynamic system](image)
3.4 RELIABILITY ENHANCEMENT THROUGH REDUNDANCY

To increase the reliability and availability of a system, a common approach of redundancy may be employed. This approach is helpful only when the cost of system failure is more or the impact of the system failure is dangerous than the cost of spare items used for redundancy [52, 53].

In the case of the refrigeration system, like domestic refrigerators, it can be employed because the eatable things that are stored inside it may become poisonous or the drugs/medicines which are stored inside it may be ruined and become dangerous for further medical or clinical purposes [54-59].

There are three types of redundancy

1. Standby Redundancy: Its name is Backup Redundancy. In this type of redundancy, an identical component or unit may be used as standby with the primary component or unit.

2. N-Modular Redundancy: It is also called parallel redundancy. In this case, the running component or unit can be multiplied by other similar types of units. In this case, the operator has the option to choose any one among them for the optimal use of the system.

3. 1-N Redundancy: In this type of redundancy only one similar type of component or system is used for the backup of N similar types of components or systems [47, 60].

Mathematically;

If, \[ R = \text{Probability of favorable outcomes} \]
\[ F = \text{Probability of un-favorable outcomes} \]
Then,

\[ F + R = 1 \]

Or,

\[ R = 1 - F \]

If redundancy is employed to the system, the above equation may be written as;

\[ R = 1 - (F1 * F2) \]

Where, \( F_1 \) & \( F_2 \) are the terms of two redundant systems in which one can functionally backup the other.

In this study, only standby redundancy ("type 1") is used to increase the reliability of the system.

### 3.5 RELIABILITY FUNCTION

The reliability function provides the probability of surviving without failure till a time of interest. In this study reliability function has been modeled assuming an exponential distribution. The exponential distribution has only one parameter, \( \lambda \) or its inverse, MTBF (mean time between the failures). Since failure rate is the simple ratio of number of failures over a specified period of time, it has been preferred over MTBF.

\[ \lambda = \frac{F}{T} \]

Where,

\( \lambda \) = Failure Rate

\( F \) = No. of failure during the test interval

\( T \) = Total test time

**Reliability Function:**

The general formula for computing reliability is;

\[ R (t) = Exp \left[ - \int_{0}^{t} \lambda(t)dt \right] \text{ (If } \lambda \text{ is a function of time )} \]
In case, if \( \lambda(t) \) is independent of time say \( \lambda(t) = \lambda \), a constant and the reliability function acquires the following form;

\[
    R(t) = \text{Exp}[\lambda t]
\]

In this study \( \lambda \)is computed and averaged for a period of fifteen year.

If \( Z(t) \) is the instantaneous failure rate;

Then,

\[
    R(t) = \text{Exp} \left[ - \int_0^t Z(t) \, dt \right]
\]

Similarly, the opposite of reliability, the unreliability function may also be specified like;

\[
    [F, \text{ as a function of } 't'] = 1 - [R, \text{ as a function of } 't']
\]

\[
    F(t) = 1 - \text{Exp} \left[ - \int_0^t Z(t) \, dt \right]
\]

In system dynamic modeling the reliability the reliability of different components of domestic VCR systems have been computed in the following manner;

\[
    \text{Reliability } (R) = \text{Exp} [\lambda \times \text{(time in year)}]
\]