Corrosion Knowledge Management Versus Corrosion Management: An Essential Tool for Assets Integrity Management

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Abstract:

Corrosion management (CM) is a relatively well known terminology to address technicalities involved in prevention and mitigation of corrosion.

However, managing corrosion must be done through an "organizational culture" within a plant that would support CM activities. This organizational culture or as we call it, corrosion knowledge management (CKM), mainly relies on managerial techniques for a better communication between both corrosion engineers and other engineers and corrosion engineers and the managers who may have a little background in corrosion.

This technique first focuses on the available "sources" and then proposes a feasible way of dealing with corrosion through these available sources by using the following principles:

- Definition of corrosion system (corrosion in the system or corrosion of the system)
- Use of information
- Transparency
- Modelling

It is proposed that based on this model for dealing with corrosion, a better understanding of corrosion and its seriousness is created and that via a feasible communication system based on CKM principles can help reduce the cost and consequences of both existing and future corrosion problems.

Keywords: corrosion management; corrosion knowledge management; integrity; corrosion; modelling.

Introduction

The approach of Corrosion Management (CM) towards the problem of corrosion is a set of techniques that are applied to prevent/mitigate corrosion. CM techniques are limited to application of cathodic/anodic protection, use of inhibitors/biocides material selection, coating/lining application and so on.

Despite having rather different applications and principles, what is common among all the CM techniques is that, with the exception of a limited group of corrosion technologists, the literature and the associated language sound like a jargon to non-corrosionists. Even, a corrosionist who has been dealing with cathodic protection would behave quite carefully. The degree of conservativeness increases when this CP specialist would deal with coating application and/or biocide selection.

The very existence of this "Babylon Tower" may sound like yesterday's news based on the each discipline uses its own terminology and nomenclatures. When it comes to corrosion, this lack of communication must be removed.

Some of the reasons for the necessity of a more proactive dialogue between corrosion engineers and technologists (collective referred to as "corrosionists") and the "non-corrosionists" are, but not limited to, the following:

- Corrosion science and technology is in essence different from all other disciplines of science and engineering in that while corrosion deals with "degradation and failure" mechanisms, all other branches of science and technology consider new technologies for making, manufacturing and production. Therefore, any non-corrosioinst who is dealing with using materials must consider their service life not only based on assumptions and expectations but real conditions of service.

- Metallic loss, wear and tear, and depreciation are "handicapped" references to what corrosion is and can become. Routine financial formats, in which a certain rate of physical depreciation is taken, are based on assumptions that under real life conditions may not always be met. To get a more realistic understanding about financial risks associated with corrosion, a more active and feasible dialogue between corrosionists and non-corrosionists is quite necessary.

- Multi-dimensional features of corrosion disasters are reflected in their serious impacts on a range of factors such as environmental economical and even community health-related. Some examples of such impacts of corrosion are given later in this paper. In this regard, care about corrosion becomes everybody's task, like knowing First Aid or Safe Driving. They are not the job and responsibility of only a few.

The lack of communication between corrosionists and non-corrosionists not only causes increase in labour and expenses in many cases, but also it results in environmental changes (impacts) whose effects are not still clear on both Nature and society.

Particularly, if the non-corrosionists are managers who have had no official training in engineering and especially in corrosion engineering, the lack of communication becomes even more important. Figure 1 schematically shows the impact:

The purpose of this paper is to present a model for material management called "Corrosion Knowledge Management" that may be applied by both corrosion experts and non-corrosionists to evaluate impacts and effects of corrosion. The methodology can also offer a way to get over environmental impacts of corrosion.

1. What is corrosion?

Corrosion according to the ISO 8044 standard is defined as "Physicochemical interaction (usually of an electrochemical nature) between a metal and its environment which results in changes in the properties of the metal and which may often lead to impairment of the function of the metal, the environment, or the technical system of which these form a part". In a sense, corrosion can be viewed as "the chemical reversion of a refined metal to its most stable energy state". During extractive processes to obtain metals out of their ores or mineral compounds, reductive processes are applied. In these processes, by giving more electrons to metallic compounds in the ore, thermodynamically stable metal in the ore is brought into a thermodynamically unstable state by the reducing processes of extractive metallurgy. In other words, by investing energy to convert the ore to metal, chemical bonds are broken; oxygen, water and other anions are removed and the pure metal is arranged in an ordered lattice whose formation requires a certain amount of excess energy, different for each metal, to be stored. It is the dissipation of this stored energy that drives the corrosion reaction. As a result, metals always are expected to reach a stable energy level by giving off additional electrons they have received during extractive metallurgical processes. This builds up the thermodynamic basis of oxidation, or more generally termed, corrosion, in metals.

2. Corrosion Mitigation

Corrosion can be mitigated by mainly two methods. One method, that we call the technical approach includes almost all known approaches towards corrosion mitigation such as applying cathodic protection, using inhibitors /biocides, etc. The other method, that we call corrosion management, enjoys a less technical however more managerial approach to corrosion. In this paper, technical approach will not be discussed. Thus we will mainly focus on corrosion management and its principles as it is a powerful tool for corrosion experts as well as non-corrosionists to deal with corrosion.

3. Corrosion Management: Managerial approach

Nowadays, there is a tremendous trend towards the belief that managers must not necessarily have an expertise about the industry in which they are acting. Now it is not hard to find an engineer –who may not have taken any particular course on corrosion acting as the corrosion

expert in industrial units. Such managers in specific matters are highly dependent on reports prepared by their colleagues and staffs, according to a pre-defined hierarchy. In fact, what happens most of the time is that they receive reports indicating that there is a problem somewhere, and that problem appears to be of such and such nature? These reports, which are routine everywhere in industry, most of the time just describe the existence of a problem but they do not give any particular idea about the type of the problem or specific cause(s) of the problem.

A common feature of such reports is that they are almost always asking the manager to decide. It is left to the manager to sign a purchase order for buying this or that required chemical, to approve a research project or to invite experts from outside. However, how does a manager recognize the severity of a problem, which has been caused by corrosion and may be beyond his own expertise, experience or even interest? How is he supposed to allocate his resources in the best way to mitigate a corrosion problem and more basically, why he must ever try to lower corrosion costs. For a manager without a deep technical knowledge about corrosion, it is almost impossible to be able to make theses technical skill-requiring decisions. On the other hand, real life conditions are not just good enough to let anybody with a deep knowledge of corrosion be the person-in-charge for decision making. So, what must be done?

This section will very briefly describe some tools by which managers, without hands-on experience in corrosion may become sure about the best strategy to be taken against corrosion Managers will be advised to form their resources in a more feasible way to mitigate corrosion, i.e., Corrosion Management (CM). Using CM principles in the petroleum industry of some countries has extended systems service life and the savings, in net present value terms, have amounted to several million dollars. Corrosion Management (CM) may be defined as the shortest, least expensive way to control corrosion in terms of resource management.

3.1. Importance of defining "sources" and "targets"

Among definitions that may be found in books for management, what one can intuitively recognize is that management is, indeed," the art & science " of balancing between what you have in hand and what you want to achieve by using the more practical, the least expensive and the shortest method. In other words, a good manager is the one who:

- Knows the resources (**R**)
- Understands the targets (**T**)
- Determines the path (**P**) to reach (**T**) via (**R**)

A good manager should try to find answers for the following questions:

- What are my resources?
- Why did I choose that/those target(s)?
- How should I get to the target(s) by using the resources?

The above questions may be referred to as "2WH" questions. In other words, a good manager first notices what he has got in hand, i.e.; **R.** This can include many factors such as human resources, financial resources, etc.; there are at least two factors that a good manager must have:

- Knowledge
- Information

Knowledge in this context means the minimum requirements one has about something, in other words, it specifically means at least an academic degree. When someone gets his degree in engineering or similar disciplines, his knowledge gives him the ability to both define and predict the state of the system.

Having knowledge is not enough, although necessary. Holding an academic degree means that through academic training, one is supposed to understand the basic facts of a scientific discipline but this doesn't necessarily mean that he has the ability to distinguish, among other things, what type of solution is the best one for a given problem. One has to update knowledge. The continuous process of renewal and updating knowledge can be called gaining "information". So for a manager, as far as his duties as a manager are concerned, information would mean a continuous process of being aware of everything related to his specific job. If he is the manager of a museum with a B.Sc. in mechanical engineering, he would definitely have to study more about his particular job and its new developments than an individual with a degree in art. The same is true when an engineer becomes a manager, either top or middle manager, of an industrial unit as he knows for sure that corrosion would be an important factor in his work but without knowing how he can re-orient his resources for finding a holistic approach against corrosion, he would always handle corrosion as cases separated from each other in space and time.

So, any processed data entering into our knowledge territory to improve it according to existing conditions is called information. To know the resources, a good manager MUST have both knowledge and information about the resources.

Why should a manager make a choice on this-and not that-target? Why he/she should select this, and only this, as the goal to achieve and not the others? There are many factors that dictate to choose certain things as goals or targets. Some of these factors are:

- Social reasons
- Political reasons
- Economical reasons
- Cultural reasons
- A combination of the above

To make it more clear, an example of building a new power plant may be used. Some of the goals (targets) that we may have in mind for such a project can be economical (solving the

problems related to the lack of electricity in the region.), political-economical (to create new jobs and work opportunities), etc. To answer the question "HOW" of 2WH questions, one has just to consider what industrial engineering literature refers to as "work scheduling", three principals of which are:

- Knowing elements of the process/project and their relationships
- Preparing executive time schedule
- Estimation of expenses and required budget

It must be said that of the three principles mentioned above, the first activity is the one that makes a project feasible. The other two factors are mechanically calculated according to the "complexity" of the project in terms of factors involved. We will see the importance of knowing elements of a project when we are introducing the concepts of CORROSION OF SYSTEM and CORROSION IN SYSTEM.

3.2. Components of Corrosion Knowledge Management as a managerial tool

Corrosion Knowledge Management (CKM) in essence doesn't differ from other management approaches. CM requires one to consider "R", "T" and "P" as well as answering 2WH questions in order to decrease unwanted effects of corrosion in industry. CKM in fact summarises what industry can eventually end up with in a more ordered, systematic way, so it is possible to find cases where industry is already using CM without necessarily naming it.

R (Resources) in CM are:

- Expert or expert team
- Capital
- Training
- Research for new anti-corrosion materials
- Research for new methods used to control corrosion
- Time
- Energy
- Information

T (Target) in CM is:

- To control corrosion to lower its costs (economical-ecological reason)

P (Path) in CKM is, then:

- Corrosion Knowledge Management

The above simply means that to combat corrosion and decrease its costs, managers must re-consider their "R"&"T" according to principles of Corrosion Knowledge Management. In other words, if they see there is a corrosion problem in their systems, first they have to check their resources to confirm that they are all there. They must see if they have facilities for doing research on corrosion-resistant materials and/or new methods for controlling that type

of corrosion. It should be noted, however, that setting targets (WHY question of 2WH questions) would determine which factor is missing in resources or which factor is worth of more timely consideration.

3.2.1. Why should we care about corrosion?

Of 2WH questions, now we know what our resources are in combating against corrosion, i.e.; we know "R" in CKM. We also know how we should reach our target, i.e.; we know that to decrease corrosion costs we must apply CKM principles. It remains now just one question: why should we fight against corrosion? Although it may seem too evident why we should try to lower corrosion costs, this section has been devoted to find an answer for this question.

Losses due to corrosion can be divided into three categories:
1) Waste of energy and materials
2) Economical Loss
    a) Direct Loss
    b) Indirect Loss
        i. Shutdown
        ii. Loss of efficiency
        iii. Product contamination
        iv. Overdesign
3) Environmental impact/health

Waste of energy and materials:
Internationally, one ton of steel turns into rust every 90 seconds, and the energy required to make one ton of steel is approximately equal to the energy an average family consumes over three months. As another example ,take a pipe line of 8-in. diameter and 225 miles(~362 Km) long and a wall thickness of 0.322 inch; with adequate corrosion protection the wall thickness could have been only 0.250 inch thus saving 3700 tons of steel as well as increasing internal capacity by 5%.

Of every ton of steel from the world production approximately 50% is required to replace rusted steel. Reports show that the loss of a sea Harrier in the Adriatic in December 1994 and partial structure loss in a 19-year-old Aloha Airlines Boeing 737 in April 1988 can be both attributed to corrosion.

Economical Loss:
Insurance companies have paid out more than US$91 billion in losses from weather-related natural disasters in the 1990s whereas direct loss of corrosion in 1994 just in the US industry was US$300 billion.

The cost of corrosion has been reported from many studies to be of the order of 4% of the GNP (Gross National Product) of any industrialised country. For instance, by considering

GNP of Australia in 1999, one can estimate a minimum loss for Australian industry, due to corrosion, to be around US$15 billion per year.

British Petroleum (BP) has reported that the cost of corrosion is equivalent to 6% of the net asset value of the company. In the power industry, It has been estimated that corrosion losses in utility steam systems amounted to about US$1.5 billion of the US$70 billion annual cost of corrosion in the USA in 1978.

The American Electric Power Research Institute (EPRI) has observed that corrosion is responsible for more than 55% of all unplanned outages and it adds over 10% to the average annual electricity bill. In fact, about 0.24% of the US GNP had been assigned to corrosion costs in power industry. Figures show that corrosion costs the US electric power industry as much as US$10 billion dollars each year. New studies on updating US corrosion cost study in year 2000 have shown that the total cost of corrosion in 1999 dollars to remediate corrosion-induced structural deficiencies of highway bridges was estimated at approximately US$30 billion. The same study showed that the current cost of corrosion protection built into new automobiles determined by auto manufacturers and other experts to be US$150 per vehicle, in fact the percentage of the GNP attributed to motor vehicle corrosion in 1998 was 0.25%.

Environmental impact/health

Table 1 shows some examples of recorded environmental/health impacts of corrosion in different years, countries and places:

3.3. Components of Corrosion Management as a managerial tool

Corrosion Knowledge Management is a method that allows the use of in-hand resources in a more profitable way to mitigate corrosion by lowering its costs. CKM has four components:

1. Modelling
2. Use of information
3. Transparency
4. Corrosion system definition (COFS/CINS)

It is worth concentrating more on the last item, i.e.; corrosion system definition. A very important aspect of solving corrosion problems is understanding the system in which corrosion is taking place. A corrosion system is defined as ***a part of universe in which corrosion occurs and is of interest to us***. Corrosion system can be considered as to be consisting of subsystems such as A, B, C, etc. If corrosion problem of each subsystem "i" is shown as corr (i) and corrosion types observed in each subsystem as a, b, c, .., one can write:

Corr (A) = $\{a_1, a_2, a_3, \ldots, a_n\}$
Corr (B) = $\{b_1, b_2, b_3, \ldots, bn\}$
Corr (C) = $\{c_1, c_2, c_3, \ldots, c_n\}$

Corrosion of a system, or briefly,***COFS*** is then defined as:
COFS = Corr (A) ∪ Corr (B) ∪ Corr (C)

Corrosion in a system, or briefly, ***CINS***, is then defined as:
CINS = Corr (i) ∩ COFS

As an example, take corrosion in an automobile. Suppose we define a car as corrosion system that is to say typical types of corrosion in subsystems of a car. In this case, subsystems can be defined as:
A= Chassis, B= Fuel system, C= brake system ,
Corrosion problems in each of the above subsystems, with important mechanisms in parenthesis, can be shown as the following:

Corr (A) = {uniform, pitting, (crevice), fretting, stress cracking, …}
Corr (B) = {(pitting), crevice, coating failure}
Corr (C) = {(pitting), crevice, galvanic, (fretting), (coating failure)}

So a project, whose goal is to solve ALL corrosion problems of a car, would have to deal with ALL of the corrosion problems in ALL subsystems, in other words, it would be a COFS approach. In this case, study of the corrosion of just a given subsystem, such as Corr (C), will be a CINS approach.

It is so important to distinguish between CINS and COFS approaches because, otherwise, many problems such as expected time span of the project or required capital for doing the project may arise. A very important point is that, in practice, it is better to define a corrosion system, by a corrosion expert, as the system with "highest risk". More often than not, a large percentage of the risk (> 80%) is found to be associated with a small percentage of the equipment item (< 20%). Once identified, the higher-risk equipment becomes the focus of inspection and maintenance to reduce the risk, while opportunities may be found to reduce inspection and maintenance of the lower-risk equipment without significantly increasing risk. In other words, to be on the safe side, it is better to choose the system of concern the one with higher risk and define COFS & CINS according to real, working conditions of the system. CKM can schematically be represented as in Figure 2:

3.3.1. Flow chart for applying CKM principals:
Figure 3 shows a flow chart that may be useful in applying CKM basics into industry. In this flowchart, practical steps that should be taken by a manager have been shown. There are three important points about this flowchart:

1. Each phase is shown by numbers in parenthesis, so step (2) comes after step (1) and step (10) is followed by step (11) and so on.

2 Phases like (3a) and (3b) just show that both activities can be taken simultaneously or, regarding the severity of the existing problem, each can be taken separately. So, if a manager

sees that there is a corrosion problem, he can have it solved by both technical solutions and managerial approach. Depending upon conditions, however, this manager may decide just to follow the "traditional technical solutions" and not a CM approach .On the other hand, (7a) and (7b) mean that if "R"s aren't just enough, the path (7a) through (9a) must be followed until we are sure about our resources. However, if we are already sure about them, we can just follow the path starting with (7b) and go on.

3. After (14), it may appear that a kind of loop has been formed. In fact, after coming to that stage, our information about our resources has been upgraded. This means that when we have come to a point that we have been able to write standards out of our experiments, our information about a certain case has been advanced. Bearing these in mind, by coming back to (7a) or (7b), we are building up our new information upon a higher ground so that in a 3 dimensional viewpoint, instead of having a "circular" loop movement, we would have a helical advancement upward every time.

4. Application of CKM principles to Environmental issues:

We need to borrow two terms from ISO 14000 terminologies: namely, environmental aspect and environmental impact. By most simple terms, environmental aspect is all parts of activities, functions, products or services of an organization (factory, plant) that are capable of interaction with the environment, whereas environmental impact is any change in environment, useful or harmful, that may have resulted, partly or generally, from activities, products or services of an organization. For example, the dusts resulting from industrial activities such as sand blasting is an example of environmental aspect whereas the problems that it causes on health are its environmental impact.

It is to be noticed that according to ISO 14000 procedures, one should always consider the most dangerous impact as it is not practical to investigate and control all environmental impacts. In this way, ISO 14000 resembles CM where "a corrosion system, by a corrosion expert, is defined as the system with highest risk". So, when considering environmental impacts, one should not only take care of the most dangerous impact from environmental point of view, but also must consider the one which is of highest risk of corrosion.

The proposed method to study environmental problems from a corrosion viewpoint is to define the environmental aspect of the case under study as corrosion, and then its environmental impacts can be divided into two subgroups, as follows:

1. Direct environmental impacts of corrosion
2. Indirect environmental impacts of corrosion

What is meant by direct environmental impacts of corrosion are those impacts that resulted just because of corrosion, leakage of dangerous liquids or gases due to weld decay or SCC are examples. On the other hand, indirect environmental impacts of corrosion are those impacts where, at first glance, corrosion does not seem to be the main cause. An example of

this sort could be energy waste in a car because of a malfunctioning that itself could have been the result of corrosion.

Study of direct environmental impacts of corrosion could be rather simple. The reason is that one would have to define just the three following items clearly:

- Definition of corrosion system (CINS or COFS)
- Recognizing the environmental aspect, that is to say, the corrosion type
- Defining and recognizing the environmental impact and determining its domain

To study the above three items, the environmental expert has to work with a corrosion expert to be able to define the system (corrosion system) and the corrosion type. It is even possible that the corrosion expert will be able to define the domain in which the environmental impact of that type of corrosion will happen. An example can be study of atmospheric corrosion in industrial areas and compare it with atmospheric corrosion in tropical areas.

Study of indirect environmental impacts of corrosion could be also focusing on three items:

1. Definition of corrosion system (CINS or COFS)
2. Recognizing the environmental aspect, that is to say, the corrosion type
3. Defining and recognizing the environmental impact and determining its domain

The main difference between studying direct and indirect environmental impacts of corrosion is that for investigating indirect environmental impacts of corrosion the following items must also be considered:

- Assessment of energy loss in the system by applying energy loss assessment methods (note that the definition of system will be very crucial in this regard)
- Determining real depreciation rate of the system by looking at the system function (the value of depreciation may not be the same as that resulted from financial studies due to the very nature of the system)
- Investigation of corrosion type
- Studying the maintenance of the system
- Monitoring and measuring corrosion in the system

Another difference is that the domain of the indirect environmental impacts of corrosion can be broader than that of the direct environmental impacts. The main reason is that the factors contributing to environmental impacts of corrosion are not limited to corrosion alone and many other factors may be also contributing. For instance, when considering environmental impacts of corrosion due to failure of a pipeline, quality of welding and post-welding processes, the soil around the pipe (for a buried pipe), the quality of coatings and linings, the topography of the place the pipe has been placed on, even the type of fertilizers used nearby (to see if a certain type of corrosion called microbiological corrosion can be stimulated) and things of this sort may be also important.

It is seen that the domain of environmental impacts of corrosion is so broad that the environmental analyst would not only need the help of a corrosion expert but also an energy auditor to help build the picture in its possible broadest way.

Conclusions

- Preserving and managing environment in terms of energy and materials resources is very important to developed countries. Although methods for energy management have been developed, no method is available yet to manage material.
- Corrosion Knowledge management (CKM) can be regarded as a method to mitigate corrosion and therefore minimize material loss.
- Principles of CKM can not only employed by corrosion experts but also by non-corrosionists and especially managers with little or no background in corrosion to find the most suitable way for resource management
- Considering corrosion type as environmental "aspect" and its results on environment as "impacts", one can distinguish between two types of environmental impacts of corrosion: direct and indirect. Although both types of impacts have the same details (defining corrosion system, defining environmental aspect or corrosion type and defining and determining of the corrosion impact on environment and its domain
- Due to multi-dimensional nature of impacts of corrosion on environment, a multi-disciplinary team containing experts in corrosion and energy auditing must help the environmental expert to define environmental aspects and impacts of a corrosion system clearly and thoroughly.

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TABLES

Table 1: Selected examples of damages caused by corrosion

Year	Place	Accident	Probable reason	Results
1967	USA	Sinking of River Queen ship	Pitting corrosion of the ship’s bottom	sinking
1970	North Sea	Platform collapse	Stress corrosion cracking (SCC)	Huge life & material loss
1985	Switzerland	Collapse of the 200-Ton concrete ceiling of an indoor swimming pool	SCC in stainless steel bars holding the ceiling, due to existing chlorine ions	12 people died, some others injured
1996	Mexico	Fire and explosion	Petrol leaking from a valve on a 1,300 m^3 storage tank caught fire, causing the tank to explode	Four people died and 16 injured. The Red Cross tended to 960 people and 10,000 were evacuated. It took two days to bring the fire under control
1997	Canada	Spill of over 35,000 liters of oil in one night	A leak in a damaged pipeline owned by Mobil oil	Large scale environmental pollution
1997	Russia	Leakage of over 1,200 tons of oil	Leakage from a ruptured pipeline	About 400 tons of oil spilled into the River Volga. A dam was built in a Tributary of the river to prevent further pollution

FIGURES

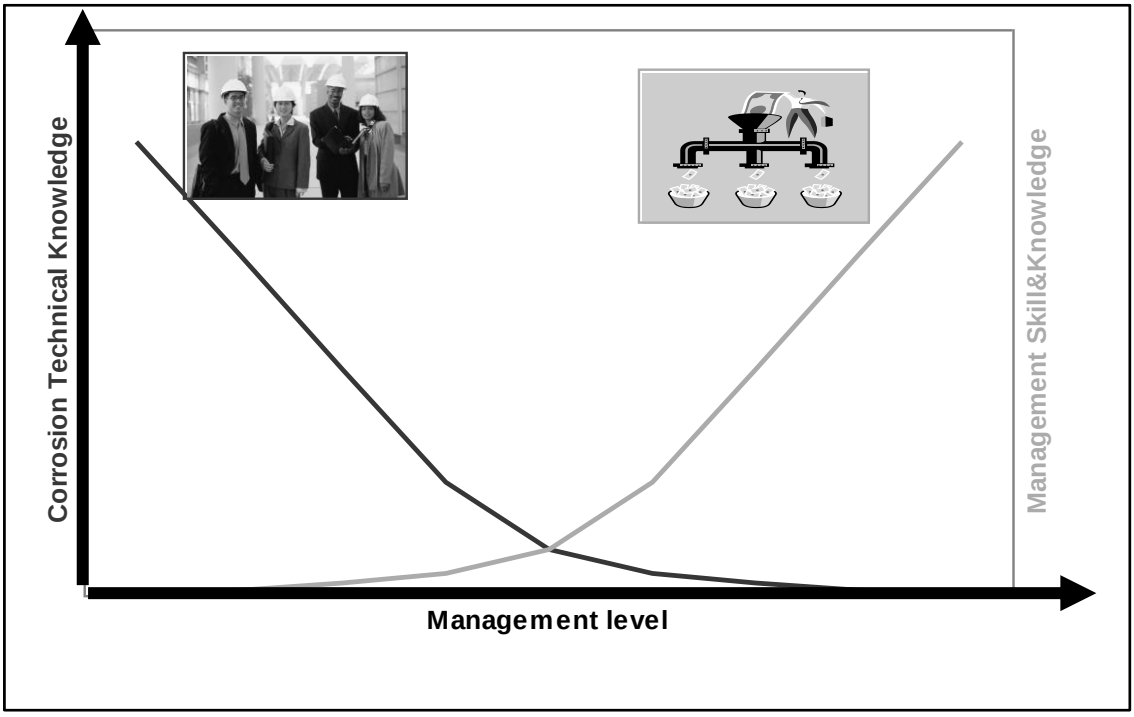


Figure 1: The bright line shows that by management levels going up, the technical knowledge is likely not to follow. The dark line shows that it may be the low echelon engineer who can lecture about the technicalities of corrosion and not necessarily the CEO.

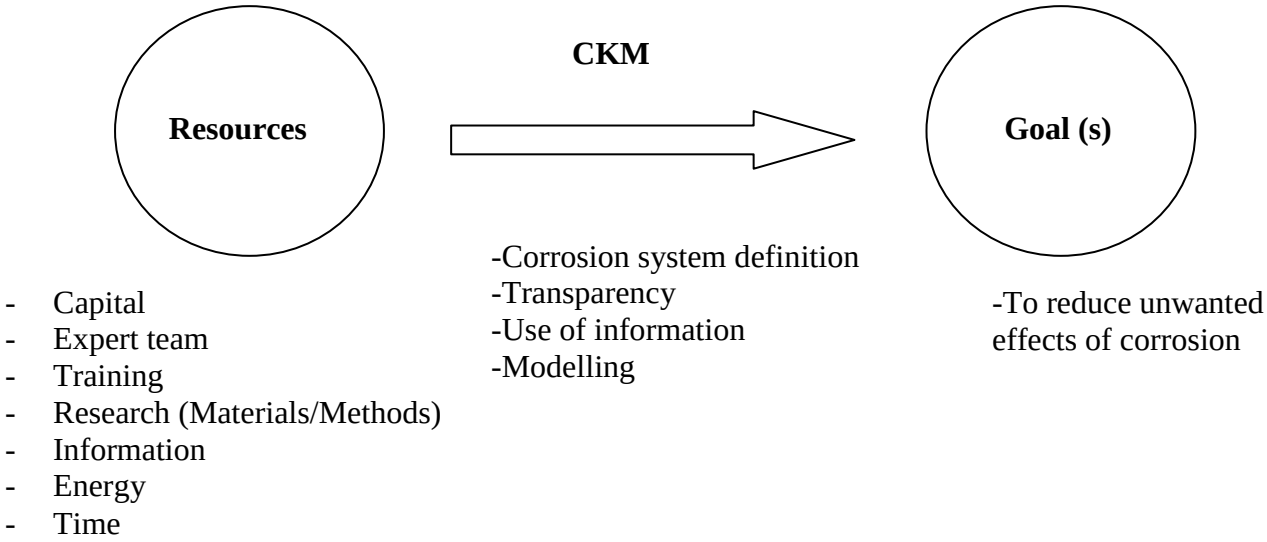
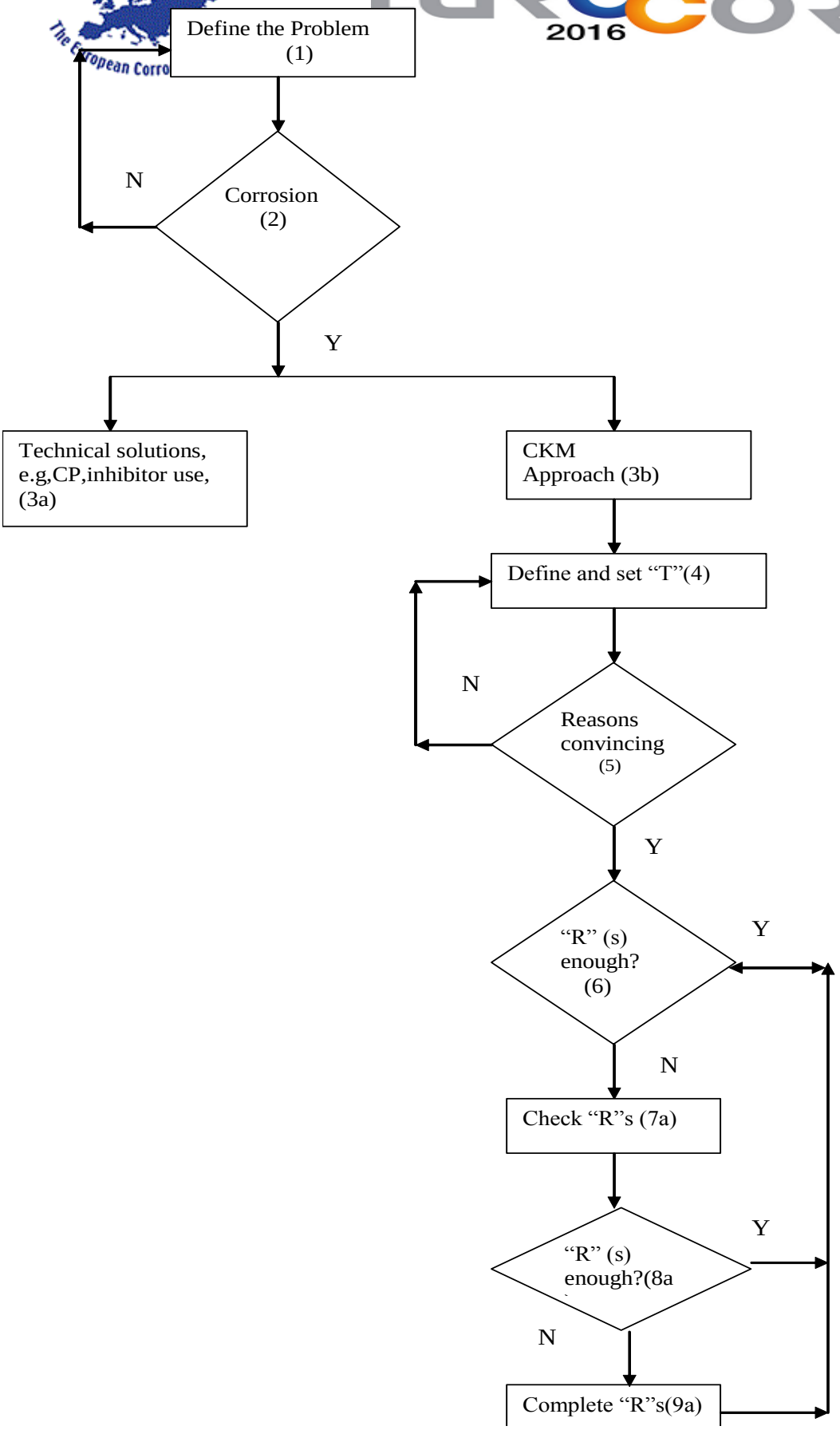


Figure 2: How Resources can be used through CKM to achieve the reduction of unwanted effects and impacts of corrosion.


Define the Problem
(1)
Corrosion
(2)
N
Y
Technical solutions,
e.g,CP,inhibitor use,
(3a)
CKM
Approach (3b)
Define and set "T"(4)
Reasons
convincing
(5)
N
Y
"R" (s)
enough?
(6)
Y
N
Check "R"s (7a)
"R" (s)
enough?(8a
Y
N
Complete "R"s(9a)

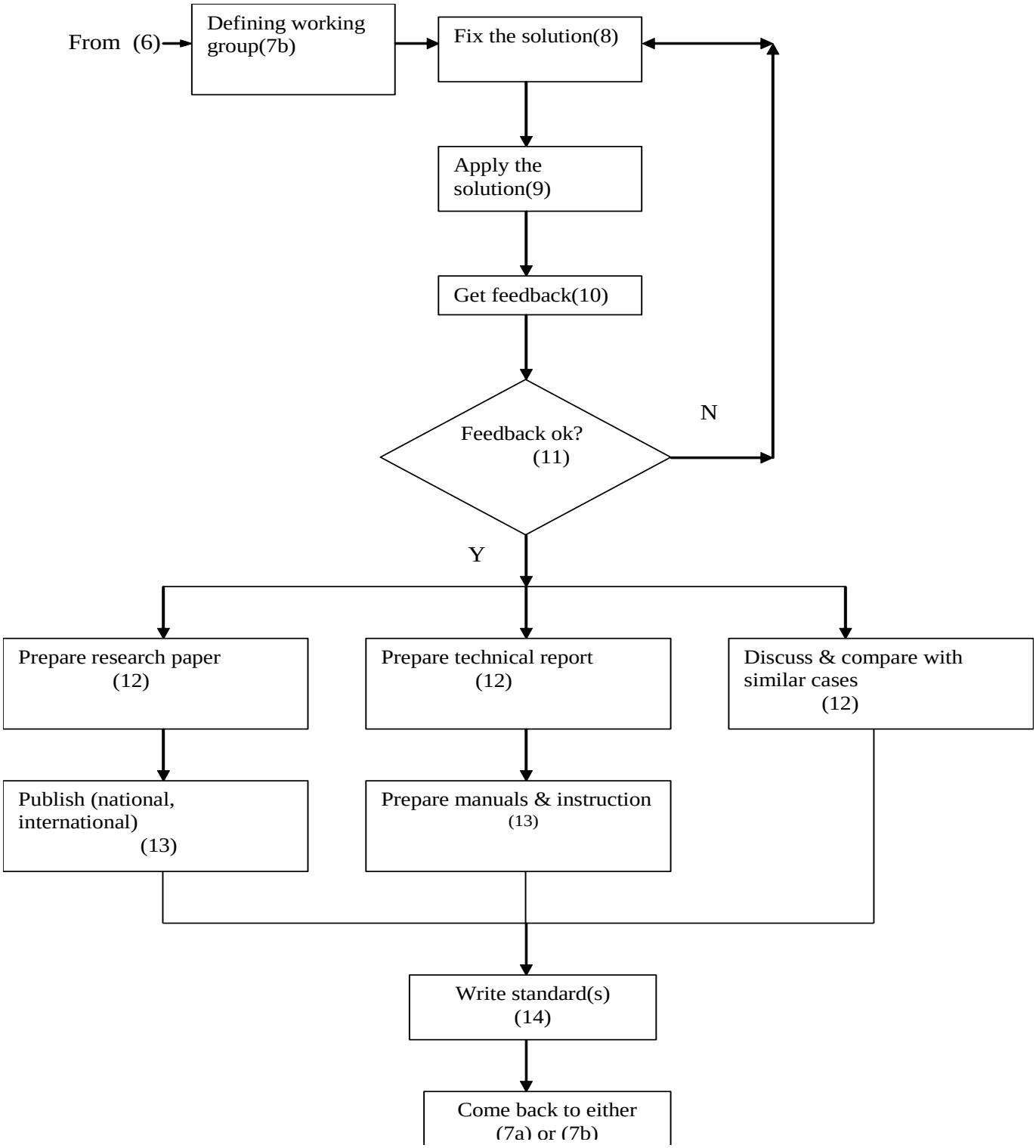


Figure 3: Flowchart for applying CKM to a system