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# Using basic equations in the assessment control of oil spill in Nigeria

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## Abstract

The large scale (xyz) oil spillage of March 24, 1988 tested spill preparedness and response capabilities of both the industry and government which proved, individually and collectively, to be wholly insufficient to control an oil spill of the magnitude.

The assessment of corporate preparedness for an oil spillage has been expressed principally in two ways. An assembly of spill response equipment is identified with or equated to a magnitude of spillage. On the other hand, the manufacturer's stated performance is equated to response capacity. These publicized levels of preparedness have been proved wrong by many a spill internationally and in Nigeria in particular, making the methods of assessment inadequate and -unacceptable. This paper introduces a new measure, the response capacity factor, THE RESPONSE CAPACITY FACTOR, for preparedness assessment defined as the ratio of a reference time duration T (a function of the sensitivity and vulnerability of the site environment) to the estimated duration T during which a spilled quantity Q (associated with an operation site) would be fully recovered within the resources of or available to the organization. The factor is based on management objective for oil spill response, environmental sensitivity and the need for its protection. It recognizes that response capacity is a function of a series of variables notably geographical location and terrain, equipment and personnel resources.

The RCF is expected to be a powerful tool for corporate planning (investment comparison, budgeting, staffing, training, operational control, etc.).

The applications of the factor for oil-spill cooperatives and national (or regional) contingency planning are also discussed.

**Keywords:** Oil spillage; Spill response; Assessment; Time duration; Environmental sensitivity; Geographical location; Magnitude; Terrain

## 1. Introduction

### 1.1. Response methods and results

The industry takes precautionary action to avoid spillage through effective maintenance. However, the frequent occurrence of spillages (from minor to major) is sufficient evidence that prevention is not or cannot be total[2]. Various corporate, cooperative, national and international Contingency Plans (CP)[4,5,6,7,8,9,10,11,12,13,14] have been established, specifying necessary actions in case of minor to major spillages. The xyz spillage' of March 24, 1989 tested spill preparedness and response capabilities of xyz, the industry and government which proved, individually and collectively, to be wholly insufficient to control an oil spill of the magnitude.

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The responses[15] to spillages can be classified into three namely:

- No action,
- Degradation enhancement (dispersal, bioremediation) or
- Recovery.

No action results when

- The spillage is undetected,
- Response would worsen the environmental or/and economic impact and
- Response resources16 (equipment, materials and personnel) are inadequate.

When no action is taken, nature is expected to completely respond and remedy the situation at its own pace. Ifeadi et al.[17] reported that insignificant action had been taken for on ground water pollution.

**1.2. Response involves**

- Preventing further discharge,
- Limiting the spread,
- Recovery of spilled oil,
- Dispersal18 of spilled oil in a water phase.
- Treatment/disposal of recovered mixture,
- Remediation/rehabilitation of impacted environment,
- Monitoring of the environment for impact assessment.

The degree of success for each of these steps and indeed the end result varies with event, time, company, environment type and the nature of spilled oil. The appendix indicates only about 25% recovery of spilled oil in Nigeria for all the efforts of spill response. Skinner' reported that the United States (USA) National Response Team was studying the adequacy of oil spill contingency plans 'nation-wide'. Such a study is absolutely necessary for Nigeria.

Some reported and studied cases of spillage are documented[19,20,21,22,23,24,25]. The degree of response success has been consistently described as 'not as effective as available techniques should allow[1,19,20].

## 2. Current methods for response capacity assessment

Two systems of assessment can be observed in the industry. The first is the listing of the quantities and capacities of equipment in stock e.g. length of confinement equipment, volume of storage tanks for recovered (treated or untreated) spilled oil, etc., The second system associates a set of anti-pollution equipment and materials with a quantity of spillage.

An assessment must take into account the objectives set in identifying and quantifying related and significant parameters of the assessed subject. The two methods stated above recognize the following parameters: -

- Response equipment technology and
- Volume of spilled oil (relating, particularly, to the second assessment method).

## 3. Deficiencies of current assessment methods

It is necessary to review the current assessment methods in the light of the (stated and supposed) objectives.

The existing response capacity assessment method fails in the light of the objectives, as follows:

Recovery objective:

- No indication of practical efficiency of equipment,
- No recognition of variability of efficiency of identical equipment in the different terrains.
- No cognizance of the dynamics of spilled oil,
- No relationship with the performance of the response personnel,

- No statement of logistics effect on time of commencement of recovery.

Low compensation objective:

- No relationship to compensation savings,
- No recognition of legal provisions of damage assessment,
- No account of locational variability of compensation,
- No account of time variability of compensation.

Minimal environmental damage objective:

- No spillage duration limitations specified.
- No (comprehensive) identification of resources at risk,
- No account of specific effect of the oil (e.g. Toxicity),
- No account for unrecoverable fractions (inhaled, ingested. Coating residue, etc.).

Controlling agency satisfaction objective:

- No agency standard equipment list exists against which to compare,
- No relationship to the baseline objective (of environmental protection).

No two spills (with time, location, nature, etc. difference) are exactly the same. Their recovery and effects would differ. The complexity of spill response can be easily demonstrated through sensitivity analysis or scatter diagram plotting of these variables.

## 4. Engineering management approach

### 4.1. Problem identification

Extensive review of the (international) industry's spill response practice confirms the non-existence of a quantification of oil spill response capacity. It further confirms the optimistic pre-incident views that gave the unfounded assurance of adequate readiness in many cases. Expert opinions in and outside Nigeria provide a further confirmation that the existing methods of assessment have no practical support. The need for the establishment of a quantification procedure is therefore confirmed.

*AIM*

The objective is to establish and define an oil spill response capacity measure.

Using legal obligations and management principles, the objective of corporate oil spill response was very clearly identified, simplified and stated. That provided the general control measure against which response effectiveness could be compared.

### 4.2. Procedure

In any assessment, it is important to identify and quantify the related (and significant) parameters. Related parameters (x) when varied will affect the attainment of the objective (y). Put mathematically

$$Y = f(x) \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Significant parameters are such that' these related parameters, risk being varied in value (with time) in important effect on the attainment of the objective. The level of importance of this effect must be quantifiable or qualifiable as acceptable or not. Represented mathematically, these imply

$$dy / dx = 0 \quad \ldots\ldots\ldots\ldots\ldots(2)$$

and

$$|dy / dx| > b \quad \ldots\ldots\ldots(3)$$

where "b' represents the acceptable limit of variation in the attainment of the objective due to a change of the parameter (x).

Response capacity concerns an identifiable area and a corresponding response organization. The potential spillage. $Q_e$ is on probabilities of spillage-provoking incidents and of various spillable quantities. Given the current difficulties of obtaining the geographical areas' sensitivity to oil and their probabilities, practical values are suggested for use. The simplified objective implies the total recovery of any spilled oil within a critical period; $T_c$. Due to the pervasive nature (related to any and all elements of the potentially impacted area) of the critical period and the inadequate data for its precise computation, a value was proposed and applied.

For the determination of a corporate capacity, a polynomial model, based on relatively recent data on corporate response, is designed. From the model, corporate-related value, $T_r$, the time expected for the company to be able to recover the quantity $Q_e$, is estimated. The ratio $T_c$ to $T_r$ is computed and termed as the current corporate Response Capacity Factor.

## 5. Discussions

### 5.1. Objective setting

Stating that the objective of oil spill response is "minimizing environmental damage", though correct, does not fully satisfy the characteristics[27] of an objective which are:

- Being specific and clear,
- Minimizing (sometimes) conflicting interpretations,
- Verifiable,
- Measurable,
- Time-related (time finiteness),
- Realistic (within available/affordable resources)2,
- The result of intermediate targets,
- The priority among other things.

Spillage can be more simply defined as "a quantity ($q_s$) of oil, placed (intentionally or accidentally) in an area not normally designed to receive the said oil at all". The objective is therefore the removal of the quantity, q of oil from the same area.

The objective can now be stated as:

To recover all stalled oil within a specified time period.

### 5.2. Planning

The purpose of planning is to prepare for future (far or near) oil spillages (of any foreseeable magnitude) by the provision of response resources which include men, money, machine, material, methods and mobility.

### 5.3. Controlling

Controlling involves comparing the result with the plan during response or after. It often calls for a specialist in environmental impact assessment or other control units. When carried out at work site it allows immediate correction saving time and reducing risk of environmental damage or future litigations.

Two non-corporate bodies, the Ministry Of

Petroleum and Mineral Resources (MPMRDPMR) and the Federal Environmental Protection Agency (FEPA), currently serve as controlling bodies for the oil industry.

The major difficulty in this function is the lack of or non-specific standards against which control is being made. The question "How clean is clean" has resurfaced at post-clean-ups internationally.

### 5.4. Coordinating

This entails the sequencing of work by teams and individuals to ensure a perfect or near perfect fitting together of the response operation. This is essentially the function of the On-Scene-Commander at the site but concern other levels of the response. Important ingredients for effective co-ordination are not limited to the management activities already discussed but include organizing, staffing and communicating.

### 5.5. Applications

The applications of the factor for corporate, cooperative, national and regional response planning and assessment enumerated after the establishment of the factor.

### 5.6. Inferences

The paper stresses the need for oil spill response capacity assessment. It highlights the deficiencies of current assessment methods with reference to the objective of oil spill response management.

It suggests the Response Capacity Factor (RCF) which is fully defined herein as a practical, objective-guided assessment tool for the industry's adoption. The problem of data availability and accessibility was highlighted for necessary attention.

## 6. The response capacity factor

### 6.1. Estimate of potential spillage

For planning purposes it is necessary to set an expected volume of spillage. The expected quantity is a function of a series of variables including operational volume handled, spillage provoking incidents probabilities, level of technology, delay in effective intervention, etc.

$$Q_e = f\,(V_t, p_i, t_j, \ldots) \ldots\ldots\ldots\ldots(4)$$

The simplest approach would be to express the expectation as

$$Q_e = k\,V \ \ldots\ldots\ldots(5)$$

Where V is static volume or flow rate and k, a fraction.

In this simplest mode, statistics of leakages are applicable. For contingency plan the simplified estimate of k would be the ratio of the largest spillage experienced over an observation period to the total quantity being handled at site at the instance of the spillage. This may, however, pose some difficulties where no spills have occurred or data is unavailable.

Three tentative (cut-off)[28] values of k are hereby suggested according to their related conditions

$k = 0.03$ (day) for continuous flow,

$k = 0.5$ of the largest capacity container (dimensionless) or

$k = 0.1$ of total storage capacity of the assembly (dimensionless).

The values could be reviewed as data become available.

The highest or relevant corresponding value of $Q_e$ becomes the practical expected magnitude of spillage from the assembly.

The parameter k is hereafter referred to as the Potential Spillage Factor (PSF) while the quantity $Q_e$ will be referred to as the Potential Spillage.

### 6.2. The factor

There is duration, $T_c$, considered as critical for an element or a group of elements, beyond which the presence of oil would have resulted in a significant impact. This duration is a function of the EIA and the sensitivity of the environment (ESI).

$$T_c = f\,(EIA, ESI) \quad \ldots\ldots\ldots\ldots\ (6)$$

In spill response, the objective (as stated earlier) is the recovery of the spilled oil. The total recovery should be within such a time $T_r$ which would be less than $T_c$ if significant impact is to be avoided. The recovery time T1 is a function of a number of factors as indicated below and obtainable through work study.

$$T_r = f\,(*) \ldots\ldots\ldots\ldots\ldots\ (7)$$

(*) = (detection, notification, alerting, strategic planning, mobilization, containment, organization, planning, co-ordination, staffing, equipment efficiency/capacity, handling/disposal, etc.)

The RCF, @, is hereby defined as the ratio of the critical time ,$T_c$, to the time $T_r$ that it takes to recover from the environment an expected quantity Q of spilled oil by an installation.

$$= T / Tr \ \ldots\ldots\ldots\ldots\ (8)$$

Given the complex composition of the environment, it is wrong to use any particular element as references. This work has therefore considered a value of $T_c$ = 12 hours as an adequate preliminary reference. The significance of this is found in the dynamic state of the spilled oil. Over 80% of the evaporation has, generally, taken place within this period as well as over 90% of spread. All other process undergone by the spilled oil, apart from dissolution occurs later during which period a virtually non-reversible damage would have been done.

Generally, the frequency of spill of the magnitude of the potential spillage is low. The value of the corresponding $T_r$ must therefore be derived through estimation. The procedure to be used is explained below:

From the records of past (one year) response e obtain the ratio, q, of the quantity, $q_r$ of recovered oil to the potential spillage of the station $Q_e$

$$q = q_r/Q_e \ldots\ldots\ldots\ldots\ldots\ldots\ (9)$$

Note the time t spent in the recovery of the quantity $q_r$

Plot the ratio q against t

This plot would give a scatter diagram. From the diagram, a relationship between q and t for the specific environment (combination of station and response) would be obtained from regressional analysis. Given the relationship, the value of t corresponding to q = 1 will give the estimated value $T_r$.

Thereafter the organization's response factor @ for the environment can be computed. This presupposes that there is a satisfactory level of correlation between q and t such that

$$q = f\,(t) \ \ldots\ldots\ldots\ldots(10)$$

The general trend (see appendix) of the q versus curve is

-for $0 < t < T_m$

Recovery would be zero or negligible attributable to strategic planning, containment, notification, mobilization, deployment, unabated equipment or team(s), organization, excessive spread, etc.

- for $T_m < t < T_t$

($T_t$ represents a threshold value)

Recovery would increase at a rate dictated by containment effectiveness, tactics, the suitability of equipment, quantity of equipment, teams knowledge / dedication / perseverance / versatility, etc.

for $T_t < t <$ infinity

Recovery rate tends to zero due to primary response limitations, natural response effectiveness.

The desirable situation would be such that

$$T_m \dashrightarrow 0,\ T_t > T_e, \text{ and } T_r < T_e$$

Optimization of the response system would give

$$@ = T_c / T_r = 1 \ldots\ldots\ldots\ldots\ldots (11)$$

Which is the expected value of the RCF.

Difficulties of this approach includes

- Current lack of sufficiently detailed reports on spill response from which the needed data could be obtained. This could be overcome by slightly modifying existing report forms and educating field (reporting) staff accordingly. See appendix 1 for the suggested format.
- Need for currency of data for effective (immediate) response capacity assessment. Records of the past one year could be used. Where data is insufficient, realistic monthly drill results can supplement.
- Reliability of information. This is no new problem. The level of reliability cannot be adversely affected by the introduction of the new assessment. Moreover, control departments and government agencies can (or have) devices to ascertain the (near) correctness of data sent to the data bank.

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## 7. Applications of the RCF

### 7.1. Corporate spillage prevention and response

Spillage prevention spans through the stages of conception, design, construction, operation and maintenance.

The RCF

- Instills in the mind, at conception, the need for environmental protection (minimizing spillages and their impact).
- Demands acceptable safety factors in design considerations,
- Calls for the use of equipment and materials compatible with the environment,
- Controls the conduct of operations such that spillages become most undesirable and
- Imposes a maintenance culture opposed to “replacement at failure”,
- Encourages regular realistic drills and exercises.

In other word, the RCF enhances systems optimization for spillage prevention and response.

The RCF, in line with management functions,

- Addresses a clear, specific, measurable, priority objective,
- Facilitates decision making,
- Enhances policy comprehension,
- Guides in planning the provision of response resources,
- Assists in the optimization of the response organization,
- Promotes human resources development,
- Enforces communication,
- Provides a system of measure and control,
- Improves co-ordination,
- Gives assurance of direction and

- Eases supervision.

From the q vs. t characteristics, the area of deficiency or inadequate effectiveness could be detected.

## 8. Government control of industry

The Ministry of Petroleum and Mineral Resources regularly (at least on an annual basis) attempts to access the capability of oil companies in oil spill response. It had relied on corporate reports, spot 'test' of response procedure and imagined effectiveness of response.

With the RCF, government agencies can, through the impositions of a minimum factor, assess the level of the hitherto subjective, response capacity.

The supervised company spill response curve, submitted prior to the test of the contingency plan, can guide government agents to specific areas for verification and their team distribution.

At the end of the exercise, areas observed to be inadequate within the response management, could be scheduled for a retest.

FEPA in articles 2.7 and 2.8, provides guidelines for contingency plan and equipment to 'lessen potential impact'.

## 9. Industry cooperative response planning

The RCF, applied to the cooperative, would indicate the area of the cooperatives high effectiveness or emphasis. By superimposing the corporate and cooperative capabilities, the actual cooperative-aided corporate capacity of the company can be assessed By setting a cooperative RCF (understandably lower than members' corporate values), depending on the expected reliance on the cooperative manpower, equipment and funding can be more easily planned. In setting the RCF, the expected spillage must exceed the corporate expectancy.

This can be done through the choice of the potential spillage factor, k.

## 10. National oil spill contingency plan

The mobilization of national resources would generally follow the confirmed inadequacy of both corporate and cooperative response capacities, indicated by a relatively low RCF in a very high $Q_c$ environment.

The determination of the first and second levels (corporate and cooperative) capacity factors and a high potential spillage will dictate the need for and the level of manpower and equipment for a national response plan. An upper limit of national spill response resources could be dictated by the RCF of a regional response organisation[31].

As mentioned under the cooperative application, the PSF, k, and the RCP, @ would be respectively higher and lower than the corporate (or cooperative values).

The application of the principle of RCF would facilitate national oil spill response planning.

## 11. Conclusion

- There is currently no satisfactory measure of corporate oil spill response capacity.
- A Response Capacity Factor (RCF) based on environmental protection, management objectives and systems optimization has been developed and is recommended for adoption by the Nigerian petroleum industry.
- The RCF is a planning and control tool usable by cooperatives companies, oil response and national contingency planners.
- A new spillage report form, though compatible with the existing three-tier format is suggested to replace that existing. It has the advantage of simplicity and being more comprehensive for management and technical analysis.
- Valuable data for analysis are not being adequately collated and published. Government should establish and fund data bank(s) for this vital purpose.

## Compliance with ethical standards

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## APPENDIX 1

### FORM SP.O1: OIL SPILLAGE REPORT (OSRI

- Site Of Spillage
  - Company: ……………………………..…..
  - OML/OPL: ……………..……………..
  - (C) Field: …………………...………..
  - Station/Location: ………………………..
  - Nature of activity: ……………………………………………………………..
  - Pollutant production rate: ………………
  - Capacities: Total storage: ………………..
  - Largest Vessel……………
  - Cause of spillage: ……………………………………………………
  - Source: (Eqt) =…………………………………….
  - Extent of spread: ………………………..
- Spillage Characteristics
  - Fluid type: ……………………………………………………….……….
  - Quantity spilled: …………………………………
  - Safety data (attach relevant documents): …………………………………………. ….
- Response
- Recovery**

| **Hours** | **Qty ($m^3$)** | **Hours** | **Qty ($m^3$)** | **Days** | **Qty ($m^3$)** |
|---|---|---|---|---|---|
| 0 | | 6 | | 4 | |
| 1 | | 9 | | 7 | |
| 2 | | 12 | | 14 | |
| 3 | | 24 | | 28 | |
| 4 | | 36 | | 56 | |
| 5 | | 48 | | 100 | |

| | Date | Time |
|---|---|---|
| Initiative of Spillage | | |
| Notification of Spillage | | |
| Commencement of recovery | | |
| Suspension of recovery | | |
| Completion of recover (100%) | | |

- Cumulative Costs (Naira)

| | **Items** | **DAYS** | | | **MONTHS** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **7*** | **14*** | **28*** | **2** | **4** | **6*** | **12*** | **Final*** |
| External | Contractors/consultants | | | | | | | | |
| internal | Equipment depreciation, repair replacement | | | | | | | | |
| | Consumable | | | | | | | | |
| | Allowances | | | | | | | | |
| Penalties | Compensation | | | | | | | | |
| | Other levies | | | | | | | | |

- General information…………………………………
- Reporting Officer:

Signature:

Title: Date:

**Table 1** Oil spill statistic in Nigeria, 1988– 2020

| **Year** | **Number of spills** | **Quantity spilled (bbl)** | **Quantity recovered (bbl)** | **Quantity left to environment (bbl)** |
|---|---|---|---|---|
| 1988 | 128 | 26,157 | 7,136 | 19,021 |
| 1990 | 104 | 32,879 | 1,703 | 31,176 |
| 1992 | 154 | 489,294 | 391,445 | 97,849 |
| 1994 | 157 | 694,177 | 63,481 | 630,636 |
| 1996 | 241 | 600,511 | 42,417 | 558,094 |
| 1998 | 238 | 42,723 | 1,542 | 41,271 |
| 2000 | 257 | 42,841 | 5,470 | 37,371 |
| 2002 | 173 | 48,351 | 2,171 | 46,180 |
| 2004 | 216 | 40,209 | 6,356 | 33,853 |
| 2006 | 151 | 9,745 | 1,645 | 8,100 |
| 2008 | 187 | 11,877 | 1,719 | 10,158 |
| 2010 | 225 | 31,043 | 6,668 | 24,375 |
| 2020 | 149 | 15,533 | 3,789 | 11,744 |
| Total | 2,380 | 2,085,280 | 535,452 | 1,549,828 |

Source: Energy publication Limited, Nigerian Petroleum News Vol. 63, September 1989 Page 3.

*APPENDIX*

**Typical spill response curve**

(QVST)