# The Instantaneous Cost of Failure

The four headlines below appeared in daily newspapers and industrial magazines during a six-week period in Australia.

**$30 Million Refinery Glitch Stalls Fuel Users**

The failure of a flange on a key piece of processing equipment meant that no gasoline was made for two weeks.

**Liquefied Natural Gas Project Back on Track after Production Train Repairs**

Nine LNG shipments were missed during the event at a cost of $300 million in lost operating profit.

**Refueling Problems Delay $250 Million Airport Terminal Operation**

Jet fuel in the pipes at this airport were contaminated with a protective anticorrosive coating left on the inside of the fuel pipes. Contaminated fuel would have gone into jet planes carrying thousands of people.

**330 Hospital Patients Suffer Cold Winter Showers**

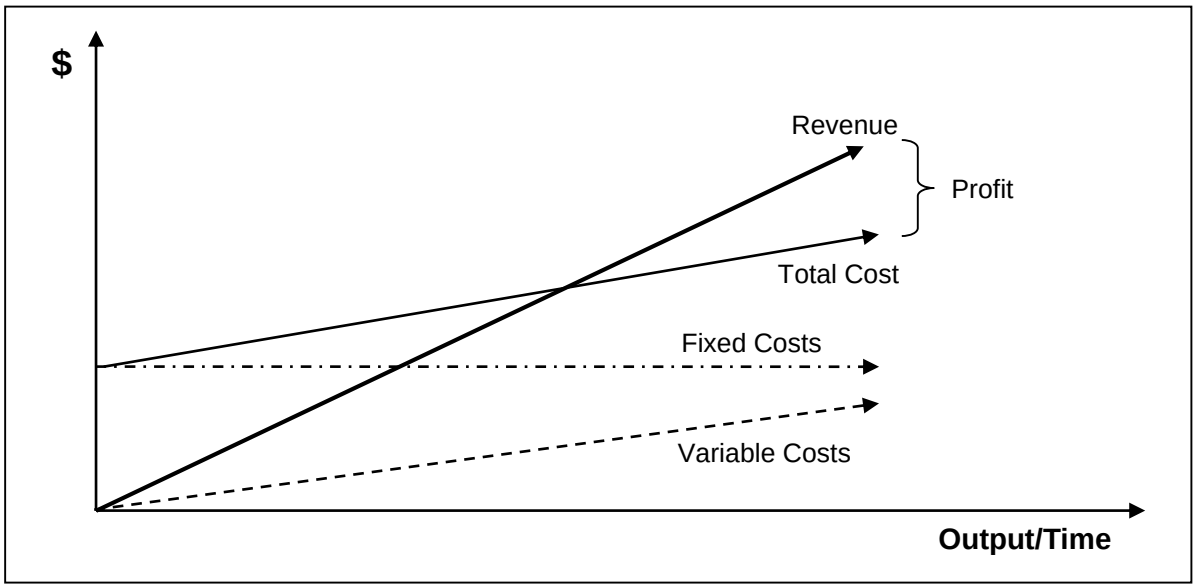
A steam boiler failed and was down for two days, putting the hospital at high risk of spreading infection to hundreds of its patients and visitors.

These failures made it into the news. Over six weeks in a lightly industrialized country, just four failures cost hundreds of millions of dollars and put lives at risk. How many failures happen that do not make the news? These real events indicate the huge financial and business consequences of failures. The cost of an incident may be no more than inconveniencing hospital patients, or it could be airplanes full of passengers falling out of the sky. The cumulative cost of equipment failure to industry and society across the world must be astronomical.

**The Effect of Failure Incidents on a Business**

Figure 1 is a simple accounting model of a business that is shown in introductory business management courses and to new accountancy students.

**Figure 1—Accounting Model for Normal Business Operations**




When an industrial company operates, it incurs fixed and variable costs to make a product that it sells. The fixed costs are what it must pay regardless of how much it produces. These include the payment of rent, managers' salaries, wages for the permanent staff and employees, insurance, equipment leases, and so on. There are variable costs as well, such as fuel, power, hired labor, hired equipment, and raw materials to make product. By doing business, the company trades and makes a profit. From the model, two simple accounting formulas can be derived. The first is how to make money in business.

**Formula 1**

Profit ($) = Revenue ($) – Total Cost ($)

If the total cost in a business is less than the revenue, then the business is profitable. The next formula explains where expenses and costs arise in business.

**Formula 2**

Total Cost ($) = Fixed Costs ($) + Variable Costs ($)

All costs are either fixed or variable. In reality, the total cost formula is incomplete because it hides the cost of waste in a business as an expected fixed or variable cost. The real total cost formula, which is not seen by new accountancy students or new management students, is as follows:

**Formula 3**

Total Cost ($) = Least Fixed Costs ($) + Least Variable Costs ($) + Loss and Waste Costs ($)

Formula 3 identifies all of the costs of losses and waste in a firm. Standard cost accounting methods identify variance from budget but do not calculate wasted and lost profits. Normal financial accounting methods include these operational failures and revenue losses as the costs of doing business, and their true value is not shown in monthly financial reports. No indication is made of the proportion of the costs that were wasted resources or lost money. Formula 4 is derived from the third formula. It explains how to lose a great deal of money in business, even when trading profitably.

**Formula 4**

Loss and Waste Costs ($/yr) = Cost of Loss Event Occurrence ($) x Frequency of Event (events/yr)

Profit disappears with every loss and waste event of any form that happens in a business. The greater the number of loss events, or the more expensive a failure, the greater the financial loss. The "cost of losses" formula takes the same form as the equation for risk in Formula 5.

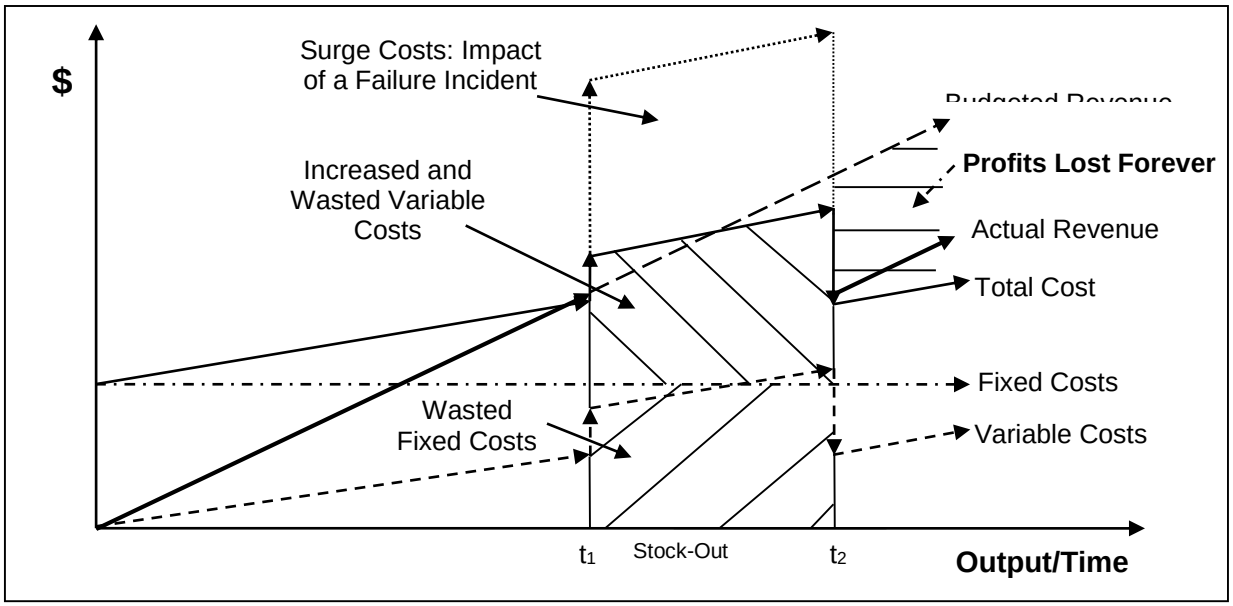
**Formula 5**

Risk ($/yr) = Consequence of Event Occurrence ($/event) x Frequency of Event (events/yr)

Risk, loss, and waste are connected. This correlation warns that if you have negative risks in your business, you will suffer all the associated costs when those events occur. Examples of failures in a business are things that are done two or three times because they were done wrong the first or second time; unplanned and unprepared tasks that take twice or three times longer to do than they should take; every safety accident; an incident that harms the environment; each time vendors supply the wrong materials; each time wrong items go to customers; and every time plant and equipment break down. These are but a few examples of how effort, time, and money are lost in business because of failures. They are preventable by controlling the responsible processes. Whether a failure is worth stopping is an economic decision based on the amount of money that a business is willing to lose.

A business pays out in full for every failure it experiences. In order to see the total financial effects of failure on a business, Figure 2 introduces a production breakdown into the model business in Figure 1.

**Figure 2—Effects of a Failure Incident on Costs and Profit**




The failure incident stops the operation at time $t_1$. A number of things immediately happen to the business. Future profits are lost because product that should be made to sell is not (although stock is sold until it is gone, which is why buffer stock is often carried by businesses that cannot afford to miss deliveries). The fixed costs continue to accumulate but are wasted because no product is being produced. Usually, operations department workers do other duties to fill in the time. Without production, some variable costs, such as energy use, fall, whereas others, such as overtime maintenance and outsourced services, rise suddenly in response to the incident. Other variable costs, such as off-site storage of raw material and contracted transport services, wait in expectation that the equipment will be back in operation quickly. These, too, are wasted

costs because they are no longer contributing to the production of saleable product. The losses and waste continue until the plant is back in operation at time $t_2$.

The crosshatched areas in Figure 2 show that when a failure happens, the cost to the business is lost future profits plus wasted fixed costs, plus wasted variable costs, plus the added variable costs needed to return the operation to production. The cost of a repair required because of a severe outage (the upper dotted lines in Figure 2) can be far greater than the profit earned from the same period of production. Not shown are the many consequential and opportunity costs that extend into the future and are forfeited because of the failure.

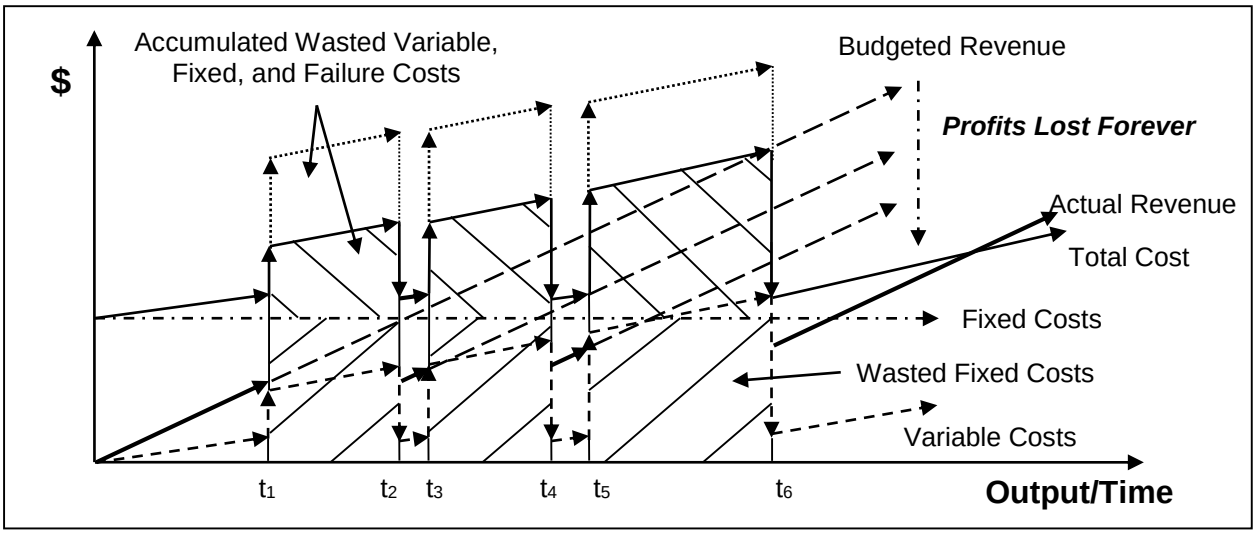
When equipment fails, people stop performing normal duties that make money and start doing duties that cost money. The production supervisors and operators, maintenance supervisors, planners, purchasers, and repairmen spend time and resources addressing the stoppage. Meetings occur, extra overtime is approved, specialist contractors are hired, the engineers investigate, and broken parts and spares are purchased to get back in operation. Instead of the variable costs being a proportion of production, as intended, during a breakdown they rise and take on a life of their own in response to the failure. Whatever money is required to repair the problem and return to production will be spent because profit is only possible when the plant is producing. Losses grow proportionally bigger as the repair takes longer or becomes more expensive and more destructive.

If the breakdown event escalates, managers from several departments will get involved—production, maintenance, sales, dispatch, finance—wanting to know about the stoppage and when it will be addressed. Formal meetings happen in meeting rooms, and impromptu meetings occur in corridors. Outside experts may be hired. Customers may invoke liability clauses when they do not get deliveries. Word may spread that the company does not meet its schedules, and

future business is lost through bad reputation. Rushed work-arounds put people at higher risk of injury. Items and men move about wastefully, and materials and equipment rush here and there in an effort to get production going. Time and money that could be better spent on business-building activities falls into the "failure black hole." On and upward the costs build, and the company's assets, resources, and people are wasted. The reactive costs and the ensuing profit loss start immediately upon failure and continue until the last cent on the final invoice is paid. Some consequential costs may continue for years after. The company pays for all of this from its income, and as the return on investment falls, it reflects to the whole world as poor financial performance.

After a failure, it is common to work overtime to make up for lost production in order to fill late orders and replenish stocks. That recovery time should have been spent on new production. Instead, it is time spent catching up on production lost because of the failure. Once scheduled time is lost to a failure, the production and profit planned from that period are gone forever. It gets much worse when there are many failures in the company. Figure 3 shows the effect of a string of failures on the operation of our model business. Repeated failures cause a business to bleed profit from a "death by a thousand cuts." The money spent to fix failures and to pay for the wasted costs leaves only poor operating profits behind. With too many failures or downtime incidents, a business becomes unprofitable.

**Figure 3—Effects of Repeated Failure Incidents on Profitability (Death by a Thousand Cuts)**




***Failure Cost Surge***

Failures and stoppages are the number-one enemy in running a successful industrial operation. The true cost of failure to a business is far greater than the loss of production plus the time, resources, and money that go into the repair. Failures cause money to be lost throughout the organization. The cost of failure includes lost revenue, repair costs, fixed and variable operating costs wasted during downtime, the cost of opportunities lost, and myriad other consequential costs that occur across the business. The organization pays for them as poor economic performance. The cost of failure is inescapable. It destroys business profits and health. Because normal accounting practices do not measure the waste and loss of failures, accountants and

managers do not see the total cost of defect and failure, so little is done to stop them happening. Yet those losses make businesses broke.

The money to pay for a failure is lost in administration, finance, operations, maintenance, service, supply, delivery, and even sales. There will be operating and maintenance costs for rectification and restitution, for stood-down manpower, for subcontracted services, for parts, for urgent overtime, for the use of utilities, for the use of infrastructure, for penalties paid because product is not available, and many other costs incurred because of the failure. The company's executive group incurs costs when senior staff get involved in managing and reviewing the effects of the failure. The information technology group may be involved in extracting data from computer systems and making software changes. The finance people get involved in the failure when they process purchase orders and make payments for invoices. Engineering incurs costs if specialist resources are used. Supply and dispatch are required to handle more purchases and deliveries. Sales representatives contact customers to apologize for delays and make alternative arrangements. Thus, failure surges throughout the departments of an organization.

Failures cause direct and obvious losses, but there are also hidden, unnoticed costs. No one counts the energy lost from cooling down operating equipment so that it can be worked on or the energy spent reheating it to operating temperature; wasted standby costs for all the idle production machinery is not even thought about; the cost to prepare equipment so that it can be safely worked on to fix a breakdown is never considered; the value of replacement raw materials wasted because of a failure disappears into the production costs; and the money spent on facility lights and air-conditioning that normally would have been off but were turned on while people worked overtime to fix a breakdown is hidden in the utility bill. No one tallies all the many needless expenses that arise just because a failure happened. Although these costs are hidden

from casual observation, they exist and strip fortunes out of company coffers, and no one is the wiser.

Yet another loss category attributable to a breakdown that never appears in the accounts are the opportunity costs, such as lost profits on lost sales, the value of customers who went to competitors, the use of skilled people who could have been doing more valuable work than fixing breakdowns, people unable to work in future from an injury they sustained during the repair, and numerous other opportunities lost by the failure event. A second type of lost opportunity occurs when parts replaced during prior breakdowns never reach their full service life because they are replaced again during another failure. If a part is meant to last 1,000 hours in service, but it is replaced after 200 hours, 80% of the previous repair cost is wasted. When parts that are meant to be trouble-free for a long time are replaced after a too short time, all of the unused expenditures on the prior repair are lost. The missing value from curtailed equipment lives is not a cost code category found in a company chart of accounts, but it should be.

The direct costs of failure, the costs of hidden waste, the opportunity costs, and all other failure surge losses are additional expenses to the normal running costs of an operation. They were bankable profits turned into lost profit. The 66 costs of failure listed below reflect many of them. If there are other failure surge costs specific to your organization, add them to the list.

- Labor: Direct and indirect
    - Operators
    - Repairers
    - Supervisors
    - Managers
    - Engineering
    - Overtime/penalty rates
- Product waste
    - Scrap
    - Replacement production
    - Cleanup
    - Reprocessing
    - Handover/hand-back
    - Lost production
    - Lost spot sales
    - Off-site storage
    - Environmental rectification
- Services
    - Emergency hires
    - Subcontractors
    - Travel
    - Consultants
    - Utility repairs

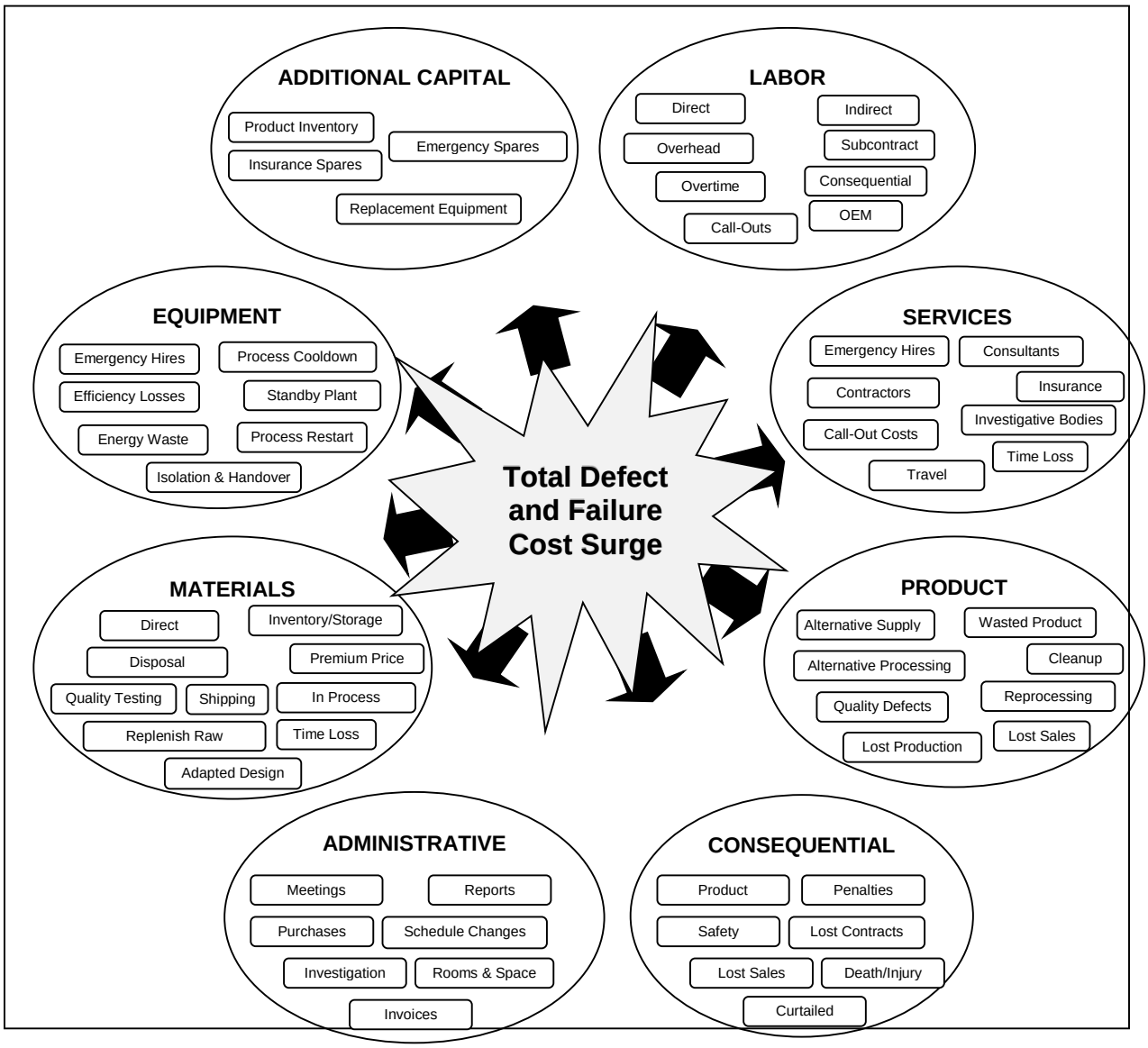
        - Temporary accommodations
- Materials
        - Replacement parts
        - Fabricated parts
            - Materials
            - Welding consumables
            - Workshop hires
        - Shipping
        - Storage
            - Space
            - Handling
        - Disposal
        - Design changes
        - Inventory replenishment
        - Quality control
- Equipment
        - OEM
        - Energy waste
        - Shutdown
        - Handover
        - Start-up
        - Inefficiencies
        - Emergency hires

        - Damaged items
- Capital
        - Replacement equipment
        - New insurance spares
        - Buildings and storage
        - Asset write-off
- Consequential
        - Penalty payments
        - Lost future sales
        - Litigation and legal fees
        - Loss of future contracts
        - Environmental cleanup
        - Death and injury
        - Safety rectification
        - Product recalls
        - Idle production equipment
- Administration
        - Documents and reports
        - Purchase orders
        - Meetings
        - Meeting rooms
        - Stationery
        - Planning, schedule changes

    - Investigations and audits
    - Invoicing and matching
- Lost value from curtailed lives
    - Lost equipment/material life
    - Labor/resources wasted
    - Outsourced services wasted

Figure 4 is a graphical representation of the total defect and failure cost surge that reverberates throughout an organization with each failure. Each loss event strips profit from the business as resources are marshalled and diverted from profit-making activities to combat the failure. These unnecessary and senseless waste and losses are cumulatively called *total defect and failure (TDAF) costs.*

**Figure 4—A Multitude of Costs Arise and Profits Are Lost Because of Defects and Failures**




***Instantaneous Costs of Failure***

In fact, the requirement to spend money on repairs and rectification of a failure arises even before the failure event happens. The moment microstructure damage is initiated in a production machine's parts, the risk of failure, with all its future TDAF costs, starts. It may be some days,

weeks, months, or even years before the microstructure-damaging event becomes a production problem, but the risk of massive future losses begins at the instance of failure initiation. The money to fix the problem, the lost income from no production, the payment of unproductive labor, the loss from waste, the handling of company-wide disruptions, and the missed future opportunities will happen when any initiated failure becomes a breakdown. The full extent of the total costs of a failure will not be known until months after the breakdown event, but they were committed to become waste and losses at the instance of failure initiation.

Even if the beginning of a failure is spotted and an outage is planned so that there is no breakdown, the outage will severely reduce operating profits. When you do maintenance instead of producing your product, your true cost of maintenance includes all the lost profit that you could have made. Maintenance stoppages of any form are expensive business costs. All of the expenditures on the repair, the extra resources needed, the lost production, and the lost opportunities are unnecessary because the defect that caused the failure did not need to happen. Creating more time between maintenance outages through higher plant and equipment reliability is certain to make your operation much more profitable.

***Costing Your Failure Consequences***

The total organization-wide instantaneous costs of failure are never seen in full. Most companies never fully investigate the far-reaching losses they incur with every failure event, and businesses miss the true magnitude of the money lost. Few companies would cost the time spent by the accounting clerk on matching invoices to the purchase orders processed because of a failure. But the clerk would not be doing that work if there had been no failure. The time and expense to

process the invoice is attributable only to the failure. The same logic applies to all failure costs—if there had been no failure, there would have been no cost and no waste. Prevent failures, and the money stays in the business as operating profit.

The true, complete business impacts of operational failures need to be valued so that you know all the money you've lost. You can wait for a failure to happen to justify calculating its TDAF costs. But it's wiser to calculate the total loss to the business if a failure does happen. The full cost of all losses from a failure incident can be calculated in a spreadsheet. Doing so requires tracing all the departments and people affected by an incident, identifying all expenditures and costs incurred throughout the company, determining the fixed and variable costs wasted, discovering the consequential costs, finding out the sales lost, and including all lost opportunities attributable to the failure and tallying them up. It's astounding when you see all the money and profit destroyed by one small production failure.

Typically, failures are repaired quickly, and then work continues as usual. If anyone inquires about the cost, the number usually quoted accounts for the repair parts and labor to fix it. Some might mention how much downtime was suffered. No one asks for the true consequential impact throughout the organization. But a business pays all failure costs and losses out of its profits. It is important to know the true failure cost so that you know its full impact on profitability and therefore can justify the efforts and actions to prevent it. You will make new fortunes with every failure you prevent.

Vast sums of money can be lost when things go wrong. In order to focus your company on preventing failures, it is necessary to identify and cost the full impact of failure on your operation. A few large catastrophes occurring close together in time, or many smaller problems occurring regularly, will destroy an organization's profitability. Too many defects, errors, and

failures will send a company into bankruptcy. Collecting all of the costs associated with a failure requires the development of a list of all possible cost categories and subcategories to identify every charge, fee, penalty, payment, and loss. The potential number of cost allocations is numerous. Each cost category and subcategory may receive several charges. In a TDAF cost analysis, you capture all of them.

The following example shows the TDAF costs for a centrifugal pump breakdown and identifies what the failure truly costs the business. In this failure, the pump inboard shaft bearing has collapsed. This bearing is on a 50 mm shaft. It is a tapered roller bearing that can be bought straight off the shelf from a bearing supplier. It is a common enough failure, and one that most people in industry would not be greatly bothered by. It would simply get fixed, and no one would think about it any more. For the example, the wages of employees, including on-costs, are paid at $40 per hour; more senior employees earn $60 per hour. The product costs $0.50 per liter to make and sells for $0.75 per liter. Throughput is 10,000 liters per hour. Electricity costs $0.10 per kilowatt-hour. All product made can be sold. The failure incident's apparent costs are tallied and recorded in Table 1.

**Table 1—Apparent Costs of a Pump Bearing Failure**

| Action No. | Description | Time (minutes) | Labor Cost ($) | Materials Cost ($) |
|---|---|---|---|---|
| 1 | Pump stops and there is no product flow | | | |
| 2 | Production process stops | | | |
| 3 | Control room sends operator to look | 10 | 7 | |
| 4 | Operator looks over pump and reports back | 10 | 7 | |
| 5 | Control room contacts maintenance | 5 | 3 | |
| 6 | Maintenance sends out craftsman | 15 | 10 | |
| 7 | Craftsman diagnoses problem and tells control room | 10 | 7 | |
| 8 | Control room decides what to do | 10 | 7 | |
| 9 | Control room issues a work order for repair | 5 | 3 | |
| 10 | Maintenance leader or planner looks the job over and authorizes the work order | 30 | 20 | |
| 11 | Maintenance leader or planner writes out parts needed on a request | 15 | 10 | |
| 12 | Storeman gathers spare parts (bearings, gaskets, etc.) and puts them in pickup area | 20 | 13 | 350 |
| 13 | Maintenance leader delegates two people for the repair | 5 | 3 | |
| 14 | Maintenance leader or planner organizes a crane and crane driver to remove the pump | 5 | 3 | |
| 15 | Repairmen pick up the parts from store and return to the workshop | 10 | 20 | |
| 16 | Repairmen go to job site | 15 | 20 | |
| 17 | Pump is electrically isolated and danger tagged out | 15 | 40 | |
| 18 | Pump is physically isolated from the process and tagged | 30 | 40 | |
| 19 | Operators drain the process fluid safely and wash down the pump | 30 | 120 | |
| 20 | Repairmen remove drive coupling and backing plate, unbolt bearing housing, prepare pump for removal of bearing housing | 90 | 20 | |
| 21 | Crane lifts bearing housing onto a truck | 15 | 7 | |
| 22 | Truck drives to the workshop | 5 | 7 | |
| 23 | Bearing housing moved to workbench | 5 | 27 | |
| 24 | Shaft seal is removed in good condition | 20 | 120 | |
| 25 | Bearing housing is stripped | 90 | 160 | |
| 26 | New bearings installed and shaft fitted back into housing | 120 | 27 | |
| 27 | Mechanical seal put back on shaft | 20 | 13 | |
| 28 | Backing plate and bearing housing put back on truck | 10 | 7 | |
| 29 | Truck goes to back to job site | 5 | 27 | |
| 30 | Crane and crane driver lift housing back into place | 20 | 80 | |
| 31 | Repairmen reassemble pump and position the mechanical seal | 60 | 80 | |
| 32 | Laser align pump | 60 | 80 | |
| 33 | Isolation tags removed | 10 | 20 | |
| 34 | Electrical isolation removed | 15 | 20 | |
| 35 | Process liquid reintroduced into pump | 30 | 20 | |
| 36 | Pump operation tested by operators | 15 | 10 | |
| 37 | Pump put back online by control room | 5 | 3 | |
| | **TOTAL** | **755** | **$970** | **$350** |

The whole job takes 12.6 hours at an apparent repair cost of $1,320. The downtime is a disappointment, but the repair cost is not too bad. Another problem solved! But wait—all of the TDAF costs are not yet collected. There are still the costs in Table 2 to be accounted for.

## Table 2—Additional Business-Wide Costs of a Pump Bearing Failure

| Action No. | Description | Time (minutes) | Labor Cost ($) | Other Cost/Loss ($) |
|---|---|---|---|---|
| 38 | Control room meets with maintenance leader | 10 | 20 | |
| 39 | Control room meets with repairmen over isolation requirements | 10 | 20 | |
| 40 | Production manager meets with maintenance leader | 5 | 10 | |
| 41 | Production manager meets with maintenance manager | 5 | 10 | |
| 42 | Production morning meeting discussion takes five minutes with 10 management and supervisory people present | 5 | 100 | |
| 43 | Production planner meets with maintenance planner | 5 | 10 | |
| 44 | General manager meets with production manager | 5 | 10 | |
| 45 | Courier is used to ferry inboard bearing because only one bearing is in stock | | 30 | |
| 46 | Storeman issues special order for bearing | 5 | 3 | Included |
| 47 | Storeman issues special order for gaskets | 5 | 3 | Included |
| 48 | Storeman issues special order for stainless shims used on pump alignment but has to buy minimum quantity | 5 | 3 | 250 |
| 49 | Storeman issues order to replenish spare bearing and raises reorder minimum quantity to two bearings | 5 | 3 | 125 |
| 50 | Storeman issues order to replenish isolation tags | 5 | 3 | 5 |
| 51 | Crane driver works overtime | 300 | 200 | |
| 52 | Both repairmen work overtime | 600 | 400 | |
| 53 | Extra charge to replace damaged/soiled clothing | | | 100 |
| 54 | 200 liters of product lost when drained out of pump and piping | | | 100 |
| 55 | Wash down water uses 1,000 liters | | | 10 |
| 56 | Handling and treatment of waste product and water | 15 | 10 | 20 |
| 57 | Pump start-up 75 kW motor electrical load usage | | | 5 |
| 58 | 13.7 hours of lost production at $2,500/hour profit | | | 32,000 |
| 59 | Account clerk issues purchase orders, matches invoices; queries order details, files documents, does financial reports (paper, ink, clips) | 60 | 40 | 20 |
| 60 | Storeman answers order queries | 20 | 13 | |
| 61 | Maintenance workshop 1,000 watt lighting on for 10 hours | | | 150 |
| 62 | Two operators standing about for 13 hours | 750 | 1000 | |
| 63 | Write incident notes for weekly/monthly reports | 30 | 30 | |
| 64 | Incident discussed at senior level three more times | 15 | 30 | |
| 65 | Stocks of product run down during outage and production plan/schedule altered and new plan advised (paper, ink, printing) | 30 | 30 | 10 |
| 66 | Reschedule deliveries of other products to customers and inform transport/production people | 30 | 20 | 10 |
| 67 | Call customers to advise them of delivery changes | 30 | 20 | 50 |
| 68 | Electricity for lighting and air conditioning used in offices and rooms during meetings/calls | | | 50 |
| | **TOTAL EXTRA COSTS** | | **$2,018** | **$32,905** |

The true cost of the pump failure is not $1,320; its TDAF costs are $36,243—27 times greater than the repair cost. That is where operating profits go when failure happens. All of the potential profits are gone, wasted, and can never be recouped. The maintenance cost of a failure is miniscule compared with the total cost of all the negative impacts on the company.

The 1:27 ratio of direct maintenance costs to TDAF costs in this example is not unusual or exceptionally high. Experience has shown that when total direct maintenance costs (i.e., the sum of labor, parts, contracted services, and overhead) are compared with the TDAF costs, the ratio often ranges between 1:5 and 1:30, depending on the equipment and operating process involved. Typically, batch processes are at the lower end, with automated and processing plants being at the higher end. This allows a rough rule of thumb to be established: the TDAF costs are around 10 times the direct maintenance costs. Because the maintenance costs to rectify a failure are much easier to collect than the business-wide losses and costs caused by the failure, this rule of thumb gives you a quick measure to gauge TDAF costs from your total maintenance repair bill.

The huge financial, time, resource, and opportunity loss consequences of failure justify applying proactive failure prevention methods. It is critical to a company's profitability that failures never start. They will only be stopped when companies understand the magnitude of the losses they suffer from failures and intentionally introduce the systems, processes, training, and behaviors required to prevent them.

### *Steps for Performing TDAF Costing*

Once a failure event is specified, there are five phases of TDAF cost analysis.

1. Define the project and its scope
2. Identify activities attributable to the failure event
3. Gather the surge costs throughout the business
4. Trace and allocate costs to activities
5. Report the analysis findings

A person with access to costing data from your accounting system and maintenance management system who is comfortable developing financial spreadsheets can perform these steps. In the case of a sufficiently large incident, a small team of people may be committed to the project. The person or core team responsible for the analysis develops TDAF cost tables, selects key people to interview, collects activity information, and identifies all costs related to the failure. Additional support can come from other knowledgeable people in the organization or from consultants. The investigation and costing process can take anywhere from a few days to a few weeks. The duration depends on the scale of the incident, the level of detail required, the complexity of an organization's processes, and the availability of resources. The investigation ought to be managed as a project using established and sound project management tools and techniques.

## Define the Scope of the Investigation

Specify the scope of the investigation and settle project management issues such as those listed below. The departmental groups involved in the failure incident and those conducting the analysis should be included in setting the scope of the investigation.

- The period of time (start, duration, and end) over which the failure incident and its effects are to be investigated
- How the investigation is resourced
- How long to spend on the analysis before a final report is provided
- The business, production, and maintenance processes to be investigated
- The accounting cost centers to be analyzed
- Costing table contents
- Who is to be interviewed to get a complete picture of the event and its costs

Identify Failure Incident Activities

Usually, it is simplest to start the investigation by finding out everything that was done to recover from the failure event. Every consequential action and its cost is required. Information can be found in maintenance work orders, purchase orders, operator and maintainer log books, process control computers, and interviews with those involved in the incident and recovery. The sample TDAF costing worksheet accompanying this book has a comprehensive list of surge costs to be traced. If you have other activities specific to the incident, include them in the analysis.

Gather All Costs of Failure

Trace all surge costs to the expenditure records whenever possible. They are undisputable proof of the real costs. These records include salaries and wages, payments for parts and materials,

replacement machinery, hired equipment, subcontracted services, and so on. It is best to get documentation of all costs so that any future disputes and queries can be readily resolved. When documents for the true costs incurred are not available, use cost assignment formulas based on the historical costs of similar activities.

Trace Costs to Activities

In this step, connect surge costs to the activities they came from. Develop a TDAF costing worksheet that matches every surge cost to its failure recovery activity. Allocate all expenditures caused by the incident—wages and salaries, maintenance purchases, outside services, and so on. Allocate all losses resulting from the failure, including production waste, energy losses, and opportunity costs.

Prepare the Final Report

Finally, produce a succinct final report explaining the effect of the failure on the organization's resources and productivity and the resulting TDAF costs incurred by the operation.

***How to Develop TDAF Cost Tables***

Follow these steps to create a TDAF cost table:

1. Identify each organizational department and work group involved in the incident.
2. Identify every person in each department or work group involved in or affected by the

incident. Determine what each person did during the incident and the total normal time and penalty time spent or lost on failure-related activities.

3. Identify each person's gross hourly normal time and penalty time cost. The gross hourly cost typically includes an overhead component of all fixed operating costs, administrative, engineering, and management costs. This overhead is on top of base salary or wage packages. For shop floor employees, the gross cost is often more than twice the hourly pay rate. If the pay rates do not include an overhead component, you will need to calculate it and add it to the rate.
4. Identify every organizational process disrupted by the incident. This includes manufacturing processes and all business and administrative processes such as accounts receivable, secretaries, inward goods receipt, forklift drivers, and so one. Identify every labor cost.
5. Find each purchase order attributable to the incident and see what was bought. Interview those people involved in the incident to identify all materials and resources purchased or used.
6. Identify every material scrap and waste resulting from the incident. Even if the material is salvageable, it is an extra cost incurred because of the incident. Calculate the cost of the material up to that point in the process (e.g., cost per kilogram, cost per metric ton, cost per part, cost per meter).
7. Identify all rework costs for salvageable materials per unit measure of the material (e.g., cost per kilogram, cost per metric ton, cost per part, cost per meter).
8. Include the expected revenue from sales of all products normally made but stopped by the failure. Production not intended for sale is not included as a failure cost, as there is no opportunity cost lost. If production not made because of the failure causes the loss of a

current customer or the loss of a definite new customer, count the foreseeable revenue lost as a cost.

9. For repaired and replaced plant and equipment, identify the wasted proportion of parts' lives for any part replaced because of the failure. The curtailed lives had value. If they worked to the end of their natural "wear-and-tear" life, no value was lost. If they failed before their natural end, then estimate the value of material, labor, and subcontracted services wasted.
10. Using a spreadsheet, create the TDAF cost tables.

Examples of the spreadsheet columns and listings used to capture failure costs in a manufacturing organization are given in Tables 3–7.

Labor Costs

- Start a worksheet to capture labor costs.
- In the first column, list each department involved.
- In the second column, list each department process affected.
- In the next column, list the position title of each departmental employee affected in each process. The same employee may appear more than once.
- In the fourth column, indicate all work each employee did because of the incident. If more than one task was done, record them all in individual rows. If other duties were done as unnecessary work but occupied time, record those as well.
- Beside that column, list the gross normal shift hourly rate.
- In the next column, list the total normal shift hours worked, or portions of an hour (e.g., 0.25, 0.5), for each person involved in or affected by the incident.

- In the column beside, list their penalty shift hourly rates.
- In the next column, list the total overtime shift hours worked at penalty rates, or portions of an hour, for each person involved in or affected by the incident.
- In the final column, calculate the total cost of all labor.

**Table 3—Labor Costs Incurred by the Organization Because of a Failure**

| Department | Process Affected | Employment Position Affected | Work Done | Normal Hourly Gross Rate | Total Normal Hours | Penalty Hourly Gross Rate | Total Penalty Hours | Total Labor Cost |
|---|---|---|---|---|---|---|---|---|
| Production | Process Line 1 | Equipment Operator 1 | Cleanup | | | | | |
| | | | Set up again | | | | | |
| | | Equipment Operator 2 | Cleanup | | | | | |
| | | | Set up again | | | | | |
| | | Production Supervisor 1 | Inspect failure | | | | | |
| | | Production Manager 1 | Inspect failure | | | | | |
| Maintenance | Mechanical | Trades Fitter 1 | Strip machines for cleanup | | | | | |
| | | Trades Assistant 1 | Assist fitter | | | | | |
| | | Maintenance Supervisor 1 | Inspect repair | | | | | |
| | Electrical | Electrician 1 | Remove burned control panels | | | | | |
| | | | Install new control panels | | | | | |
| | | Electrical Supervisor 1 | Inspect repair | | | | | |
| | Stores | Storeman 1 | Receive/store new panels | | | | | |
| | | Maintenance Engineer 1 | Inspect failure | | | | | |
| | | | Inspect repair | | | | | |
| | | Maintenance Manager 1 | Inspect repair | | | | | |
| Administration | | Secretary 1 | Compile failure report | | | | | |
| | | Senior Executive Manager 1 | Attend site meeting | | | | | |
| Finance | | Accounts Receivable 1 | Process purchase orders/invoices | | | | | |
| **TOTAL COST** | | | | | | | | |

Purchased Materials and Services

- Start a second worksheet to capture purchases of materials, goods, hired equipment, subcontractors, service specialist, and so on.

- In the first column, list each department involved.
- In the second column, list each department process affected.
- In the third column list all of the plant, equipment, and machinery affected by the incident. The costing goes as far as recognizing the use of paper and ink for reports.
- In the fourth column, list the materials and purchased services used.
- In the next column, list all invoiced costs, or portions of invoiced costs, for every plant, equipment, and machinery affected by the incident.
- In the final column, calculate the total cost of all purchases.

**Table 4—Purchased Materials/Services Costs Incurred Because of a Failure**

| Department | Process Affected | Plant, Equipment, and Machinery Affected | Parts, Materials, Services Purchased | Total Invoiced Purchases | Total Cost |
|---|---|---|---|---|---|
| Production | Process Line 1 | Manufacturing Equipment 1 | | | |
| | | Manufacturing Equipment 2 | Electrical control cabinet | | |
| | | | Electrical motor draw | | |
| | | | Electrical cable | | |
| | | | Process computer programmer | | |
| | | Manufacturing Equipment 3 | | | |
| | | Forklift 1 | | | |
| | | Production Building 1 | Power supply cabinet | | |
| Maintenance | Mechanical | | Mechanical consumables | | |
| | | | Nuts and bolts | | |
| | Electrical | | Electrical consumables | | |
| | Stores | Facsimile | Paper | | |
| Administration | | Printer | Report materials—paper, ink, binder | | |
| | | Facsimile | Paper | | |
| Finance | | Printer | Purchase orders | | |
| **TOTAL COST** | | | | | |

Material and Product Waste

- Start a third worksheet to capture material and product waste costs.
- In the first column, list each department involved.
- In the second column, list each department process affected.

- In the third column, list all the plant, equipment, and machinery affected.
- In the fourth column, list each item of material waste identified for the equipment.
- In the fifth column, list the unit cost of each waste at its value up to that point in production (e.g., cost per kilogram, cost per metric ton, cost per part, cost per meter). Add any additional unit cost for rework of salvable items to the initial value.
- In the next column, indicate how much of each waste unit was present.
- In the final column, calculate the total of all material waste.

**Table 5—Material and Product Waste Incurred Because of a Failure**

| Department | Process Affected | Plant, Equipment, and Machinery Affected | Materials, Products Wasted or Reworked | Unit Cost of Waste/Rework | Total Wasted/Reworked Units | Total Waste Cost |
|---|---|---|---|---|---|---|
| Production | Process Line 1 | Manufacturing Equipment 1 | Raw materials for the line | Cost per kilogram | | |
| | | | Product in Equipment 1 | Cost per unit | | |
| | | Manufacturing Equipment 2 | Product in Equipment 2 | Cost per unit | | |
| | | Manufacturing Equipment 3 | Product in Equipment 3 | Cost per unit | | |
| | | Forklift 1 | | | | |
| | | Production Building 1 | | | | |
| Maintenance | Mechanical | | | | | |
| | Electrical | | | | | |
| | Stores | Facsimile | | | | |
| Administration | | Printer | | | | |
| | | Facsimile | | | | |
| Finance | | Printer | | | | |
| **TOTAL COST** | | | | | | |

Lost Opportunity Costs

- Start a fourth worksheet to capture lost opportunity costs.
- In the first column, list each department involved.
- In the second column, list each department process affected.
- In the third column, for each process, record the opportunities lost because of the incident, such as the following:
    - Lost sales that would have definitely happened
    - Double handling, where the second handling prevented normal work
    - Production volume lost because of downtime, rework, and time lost to cleaning of equipment and production lines
    - Medical expenses for accident victims
- In the next column, indicate the unit cost of each lost opportunity (e.g., cost per kilogram, cost per metric ton, cost per part, cost per meter).
- In the next column, indicate how much of each lost unit was present.
- In the final column, calculate the total of all lost opportunities.

<END>

**Table 6—Lost Opportunity Costs Incurred Because of a Failure**

| Department | Process Affected | Opportunity Lost | Unit Cost of Lost Opportunity | Units Lost | Total Lost Opportunity Cost |
|---|---|---|---|---|---|
| Production | Process Line 1 | Profit on sales from 24 hours of lost production | | | |
| | | Curtailed lives of repaired and replaced equipment | | | |
| Maintenance | Mechanical | | | | |
| | Electrical | | | | |
| | Stores | | | | |
| Administration | | | | | |
| Finance | | Money for Process Line 1 cost reduction spent on repair | | | |
| Sales | New Customer | Future sales revenue | | | |
| **TOTAL COST** | | | | | |

Summary of Costs

In a separate worksheet, create a summary spreadsheet showing the separate cumulative costs for each category and the grand total cost.

**Table 7—Summary of Costs Incurred Because of a Failure**

| Cost Category | Final Cost |
|---|---|
| Labor Cost | |
| Purchased Materials/Services Cost | |
| Material and Product Waste Cost | |
| Lost Opportunity Cost | |
| **TOTAL TDAF COST** | |

***Risk Rating with TDAF Costs***

Once the TDAF costs for your equipment are estimated, Process 1 is completed. The TDAF costs provide honest identification of the total value of losses and waste that a company suffers from an equipment failure. Putting a believable business value to failure is important. Doing risk mitigations without knowing the benefit of addressing the risk makes managers uncomfortable. They need a credible value for their financial investment modeling and business case justification. Once all of the money lost by a failure event is known, company management has the correct information to make sound decisions regarding appropriate actions to take. TDAF costing provides a believable and traceable monetary value for managers to use because the costs are drawn from the company's own accounting and business systems. None of the costs are wild guesses; rather, they are estimates calculated from real details. Managers can be more confident in making good decisions when they have a true value of the consequences they must address.

The consequential TDAF cost value of risk found in Process 1 is used in Process 2. With the cost consequences of a failure known accurately, the only remaining uncertainty in a risk analysis is the frequency of a failure event. This represents the likelihood of it occurring in the operation being analyzed. In Process 2, you will identify the event likelihood and determine the current business risk from your equipment failures.