Chapter 4: 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 4.1 is a simple accounting model of a business that is shown in introductory business management courses, and to new accountancy students.

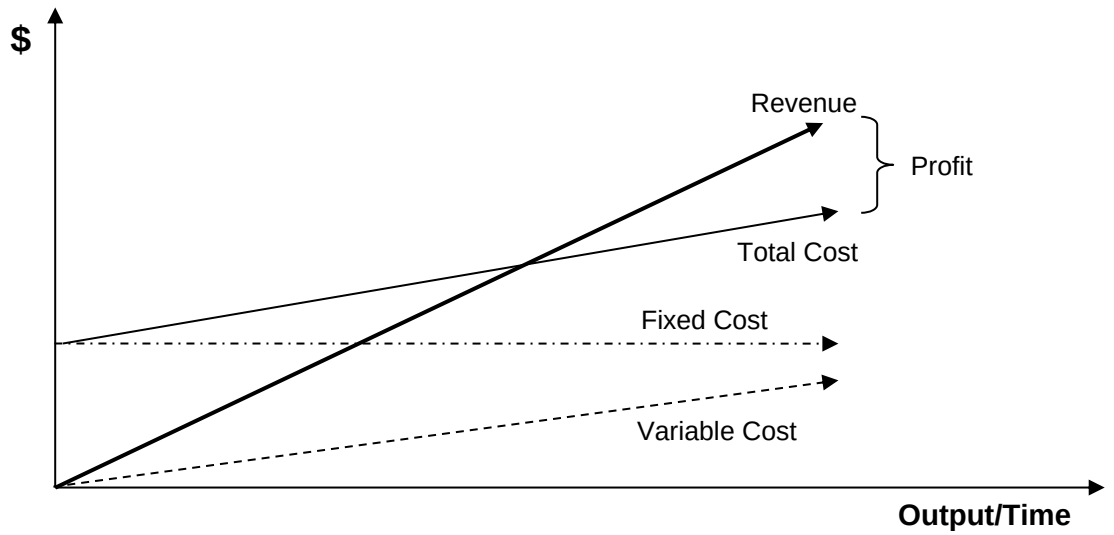

Figure 4.1—Accounting Model for Normal Business Operations

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 4.1

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

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

Formula 4.2

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

All costs are either fixed or variable. 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 4.3

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

Formula 4.3 identifies all 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 and lost money. Formula 4.4 is derived from the third formula, it explains how to lose a great deal of money in business, even when trading profitably.

Formula 4.4

Loss and Waste Costs ($/yr) = Cost of Loss Event Occurrence ($) x Frequency of Event (/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 4.5.

Formula 4.5

Risk ($/yr) = Consequence of Event Occurrence ($/event) x Frequency of Event (event/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 done two or three times because they were wrong the first 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 wrong materials; each time wrong items go to customers; and every time plant and equipment breakdown. 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 a business is willing to lose.

A business pays out in full for every failure it experiences. To see the total financial effects of failure on a business, Figure 4.2 introduces a production breakdown into the model business in Figure 4.1.

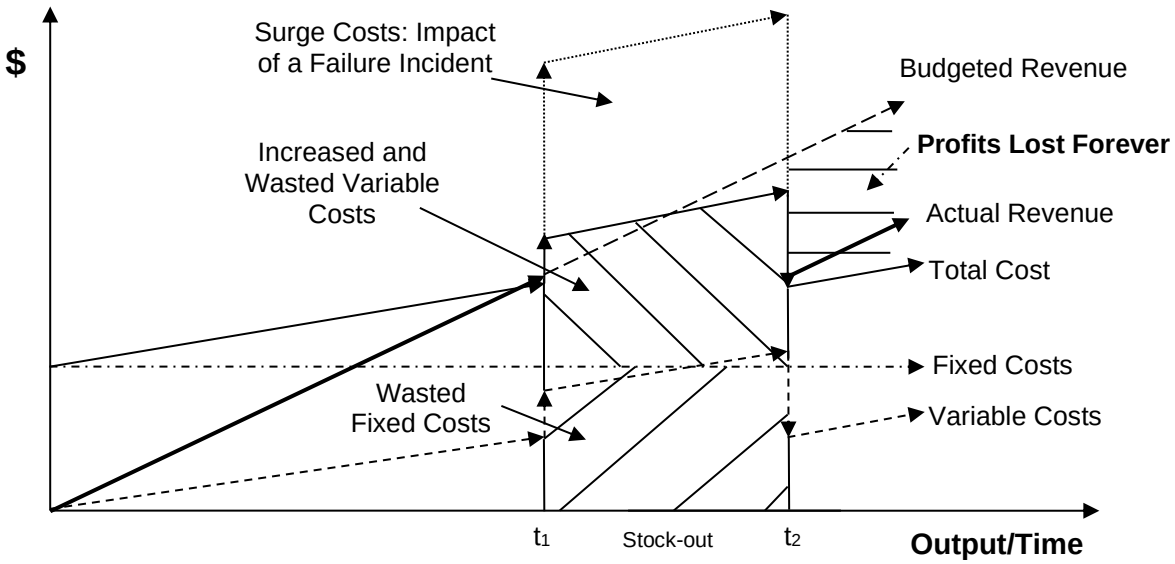

Figure 4.2—Effects of a Failure Incident on Costs and Profit

The failure incident stops the operation at time t_1. Several 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, operation department workers do other duties to fill in the time. Without production, some variable costs, like 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 making saleable product. The losses and waste continue until the plant is back in operation at time t_2.

The crosshatched areas in Figure 4.2 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 impact of a repair required because of a severe outage (the upper dotted lines in Figure 4.2) 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 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 workarounds put people at higher risk of injury. Items and men move about wastefully, and materials and equipment rush here and there 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 additional overtime to make up for lost production 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 is gone forever. It gets much worse when there are many failures in the company. Figure 4.3 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.

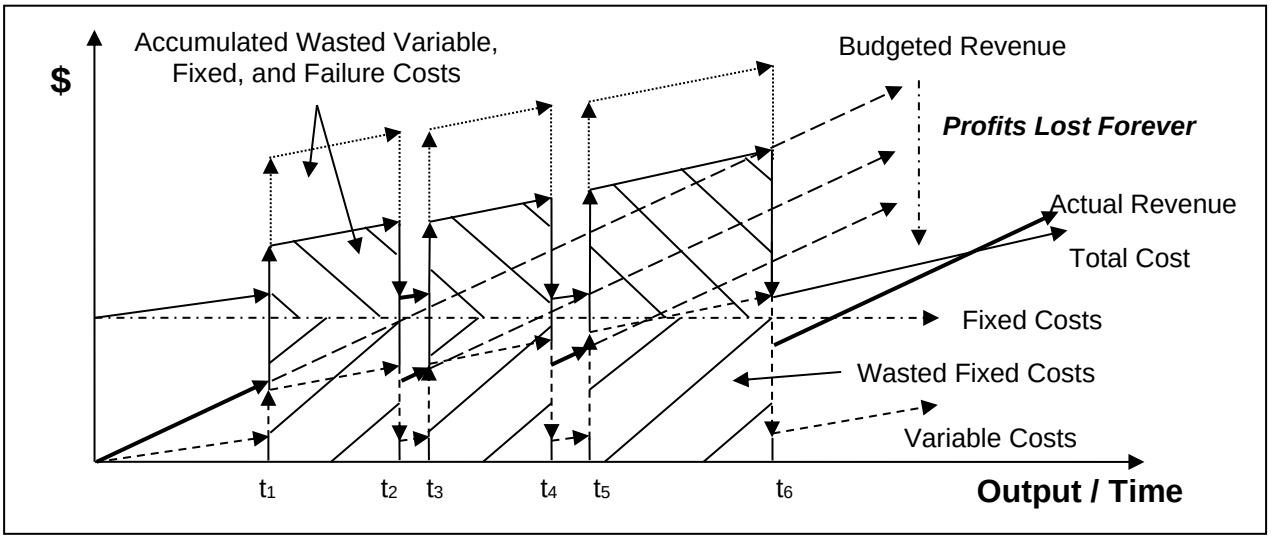

Figure 4.3—Effects of Repeated Failure Incidents on Profitability (Death by a Thousand Cuts)

Failure Cost Surge

Failures and stoppages are the number-one enemy in running a successful industrial operation. The true cost of failure 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 in prior breakdowns never reach full-service life before they are again replaced 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 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
  - Supervisory
  - Management
  - 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 charges
  - 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 4.4 is a graphical representation of the total defect and failure cost surge that reverberates throughout an organization with each failure.

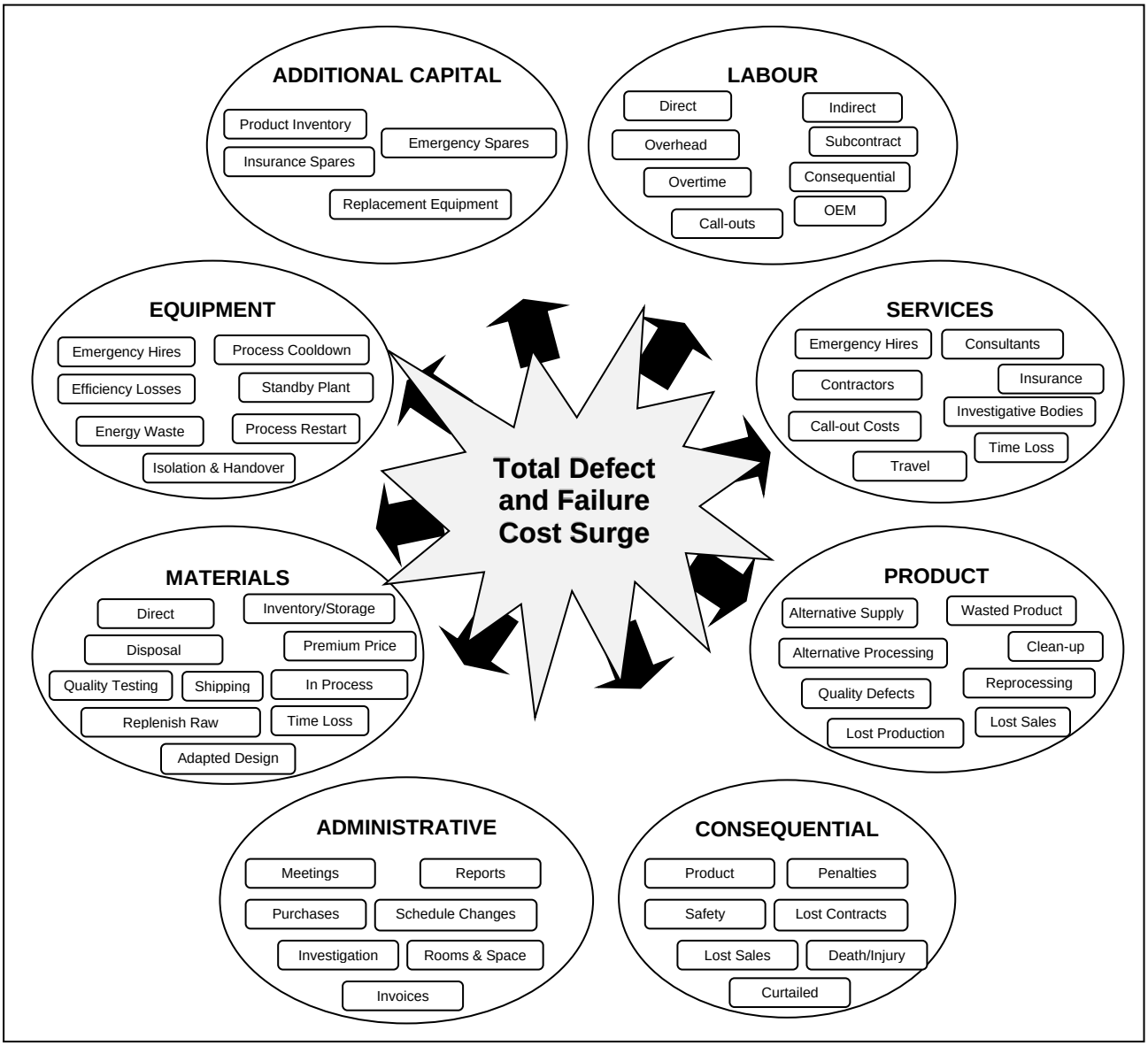

Figure 4.4—A Multitude of Costs Arise and Profits Are Lost Because of Defects and Failures

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.

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 failure will not be known until months after the breakdown event, but they were committed to become wastes 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 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 raised 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 queries 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. 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 worked example below 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-millimeter (2 inch) 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 anymore. 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 products made can be sold. The failure incident's apparent costs are tallied and recorded in Table 4.1.

Action No.	Description	Time (Minutes)	Labour 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 raises 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 men 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	
13	Bearing housing moved to work bench.	5	27	
24	Shaft seal is removed in good condition.	20	120	
25	Bearing housing stripped.	90	160	
26	New bearings installed and shaft fitted back into housing.	120	27	
28	Mechanical seal put back on shaft.	20	13	
29	Backing plate and bearing housing put back on truck.	10	7	
30	Truck goes to back to job site.	5	27	
31	Crane and crane driver lift housing back into place.	20	80	
32	Repairmen reassemble pump and position the mechanical seal.	60	80	
33	Laser align the pump.	60	80	
34	Isolation tags removed.	10	20	
35	Electrical isolation removed.	15	20	
36	Process liquid reintroduced into pump.	30	20	
37	Pump operation tested by operators.	15	10	
38	Pump put back online by control room.	5	3	
	TOTAL	**755**	**$970**	**$350**

Table 4.1—Apparent Costs of a Pump Bearing Failure

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 the TDAF costs are not yet collected. There are still the costs in Table 4.2 to be accounted for.

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

Table 4.2—Additional Business-Wide Costs of a Pump Bearing Failure

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 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.