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Determination of the Financial Impact of Machine Downtime on the Australia Post Large Letters Sorting Process

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ABSTRACT

Machine downtime, whether planned or unplanned, is intuitively costly to manufacturing organisations, however is often very difficult to quantify. Costing processes are rarely undertaken within manufacturing organisations. It has previously been estimated that 80% of industrial facilities were unable to accurately cost downtime, with many facilities underestimating the total cost by a factor of 200-300% (Crumrine and Post 2006). It was also acknowledged that the lack of practical guides has hindered costing procedures of any nature being implemented more readily (Dale and Plunkett 1995). Models that did exist rarely considered more than a subset of the costs identified elsewhere, leading to overly conservative estimations. In addition, because cost definitions are not consistent, methodologies for evaluating and quantifying individual costs have not previously been adequately defined. The work outlined in this paper has aimed to develop the first comprehensive methodology for determining the cost of downtime, with particular application to the Australia Post's automated mail processing machines. The method presented may be applied to any manufacturing environment which would benefit from a more complete understanding of the magnitude of the cost of machine or process downtime.

KEY WORDS: *Cost of downtime*; *Australia Post; Mail processing; Downtime*

INTRODUCTION

Machine downtime, whether planned or unplanned, is very costly to most manufacturing organisations. Aside from the obvious costs of idle production labour and spares value, the cost of downtime extends to other resources within the facility, as well as to the organisation as a whole. For many organisations however, these costs are very difficult to quantify. The available literature found that while few organisations actually cost downtime, even fewer valued more than one or two of the most obvious costs. Because of this, the cost of downtime quoted was often overly conservative, reducing the incentive to address root causes of failure. Australia Post (Post) was in the same situation with its automated Mail Processing Equipment (MPE). While Post recognised that downtime was a significant burden to the organisation, no attempt had been made to understand in a quantitative manner, how downtime affected organisational costs. Because of the nature of mail processing, downtime costs proposed previously were considered unrealistic, and no single figure was able to be reliably used throughout the entire organisation. The aim was to develop a common downtime costing method and framework, with particular application to the Flat Mail Optical Character Reader (FMOCR). The determined value of downtime was required to be transparent and defendable; the objective for Post was to be able to use the figure both for analysis and justification. The methodology had to be able to survive scrutiny from engineering, production, and financial sides of the organisation. In addition, the model developed was required to be adaptable to other types of MPE within the network. The development of a suitable cost of downtime is the subject of this paper.

ORGANISATIONAL NEED

A major concern of Post was the poor availability during operational windows and the high maintenance costs associated with the upkeep of the FMOCR. Although both failures and maintenance time have decreased over the last 24 months, which is consistent with the run-in period of the machine, the performance of the machine was still poor in comparison to the original specifications. Previous projects had attempted to eliminate defects within the FMOCR, and have had varying degrees of success. A number of these areas had been identified by technicians maintaining the machine and tended to be site specific. While many suggestions were the result of legitimate concerns with the machine, there has always been great difficulty in justifying the changes. Many projects did not increase machine performance in easily quantifiable terms such as letter throughput, but rather targeted machine availability, mean runtime between failure (MTrBF), reduction of scheduled maintenance time, or decreased fault diagnostic time. The value of such changes was therefore difficult to fully quantify. In addition, without understanding the quantitative effects that such changes have on the organisation, activities could not be appropriately prioritised for resources. It has historically been difficult to separate those that have the greatest effect from those that, while well-intentioned, do not make a substantial difference. The purpose of determining the cost of downtime therefore also served to assist in the prioritisation of proactive maintenance activities.

INTRODUCTION TO THE FMOCR

The FMOCR is one of the key automated mail processing equipment employed by Post to process and deliver the 4.97 billion domestic mail articles and achieve their 94.0% on time delivery obligation. Post owns and operates eight FMOCRs in mail centres located in major capital cities across Australia. These machines are used to process large-letters, or flat mail items (flats). The mail items may vary in size from 138mm to 360mm long; 88mm to 260mm wide; and up to 23mm thick. All mail items must be less than 500 grams. The FMOCR does not process Express-Post™ mail items.

The FMOCR is a complex high speed mail processing machine that has in excess of 2,178 unique replaceable components or sub-assemblies. The machine design is modular, and varies in capacity according to anticipated mail centre demand. The largest of the machine variations are located in Sydney West Letters facility (SWLF) and Dandenong Letters Centre (DLC). A slightly smaller machine is located in Northgate Mail Centre, Brisbane. The smallest variation of the FMOCRs are located at Perth Mail Centre (PMC) and Adelaide Mail Centre (AMC).

Because of the nature of mail processing, mail may be delayed for a variety of other reasons apart from machine breakdown. This could be because of staffing or resourcing difficulties, transport breakdown, power failure, or incorrectly sorted or lost mail. Because of this, there is no direct relationship between the percentage of large letters delivered late, and machine availability. This has serious implications for costing some of the less tangible impacts of downtime, such as lost goodwill and customer loyalty.

KNOWLEDGE GAPS IDENTIFIED IN LITERATURE

Fundamentally, the application of downtime costing in industry is not addressed well within literature. While generic costs are listed, the reality of what these represent within the manufacturing industry have been rarely discussed. The practices of other costing models, such as those used for quality costing, have gained significantly greater attention. Even so, it is still acknowledged that the lack of practical guides is hindering costing procedures being implemented more readily (Dale and Plunkett 1995). In addition, the quantitative effects of the costing parameters have not been compared, either within the mail processing industry, or between industries – it is unknown which factors are the greatest cost drivers prior to undertaking an analysis. It is therefore difficult to ascertain which cost factors require the greatest attention. Many costs, while deliberately mentioned within literature, may be insignificant when quantified. While others, which may prove to be major cost drivers, have not garnished as much attention.

Because no standard definitions exist for cost factors, each can be interpreted in several different ways depending on the perspective of the organisation. While misinterpretation of costs is one concern, another is that because cost definitions are not consistent, methodologies for evaluating and quantifying individual parameters have not been adequately defined. Examples of data sources used for evaluating parameters and how well those sources represented the real cost are relatively rare within literature. Because of this, every costing process undertaken has had to start from the beginning, defining both what the cost parameters reflect within the organisation, and how those parameters should be evaluated given the data sources available. Even though every organisation's reporting structure is different, all are required to output comparable data. It is therefore conceivable that, while costing procedures cannot be directly adopted from one organisation or industry to another, applied procedures could be adapted between organisations – providing both a framework for quantifying the individual costs, as well as a basis for comparison of the cost values. The lack of a sound, transparent and adaptable model is the basis for the work presented in this paper.

In addition, there appears to be limited understanding of how downtime affects quality costs. As quality costs are customer driven, the costs of process downtime has little mention, other than to say that it is a category of failure costs. It is intuitive however, that for a process that incurs significant volumes of downtime, the cost of quality would be considerably affected. With regards to the FMOCR, the nature of these costs has been considered.

DOWNTIME COSTS SPECIFIC TO POST

A key step in the identification and analysis of downtime costs was the application of the generic costs identified to the FMOCR and the large letters sorting process. In order to realize how the costs related to the FMOCR, an understanding of the activities undertaken and the costs incurred during downtime events was required.

It was realised early on that the types of activities undertaken during a downtime event were determined by the length of time the machine was inoperative. Longer duration events were more likely to involve more activities to restore the machine, and greater costs associated with limiting the effect of the failure. Shorter duration events were more likely to result in operations staff waiting for the machine to be restored, and therefore interrupt the mail processing. In addition, it was also realised that some cost parameters were not so much affected by a single downtime event, but rather the cumulative total of downtime across the entire production shift. Other costs identified were incurred independently of the volume of downtime, and were associated with a specific incident. These costs are discussed in the following sections within the context of the large letters sorting process.

Downtime Costs affected by Downtime Event Duration

Figure 1 shows the types of activities identified for a typical downtime event, and how these vary with the length of the event. As can be seen, for very short duration events, production staff were considered most likely to be the ones repairing the machine. Longer duration events would require maintenance staff involvement. For events greater than ten minutes, production staff would either continue mail sorting by hand, or would use older, legacy MPE to process the mail volume. Downtime events greater than an hour were expected to require escalation to the relevant equipment specialist for assistance.

Figure 1 shows that as the length of a downtime event increases, the effect to other sections of the organisation also increases. For downtime events shorter than 5 minutes, only production staff were likely to be affected, whereas for longer duration events, maintenance personal and even management maybe affected. Downtime durations greater than an hour were expected to have a direct impact on the performance of downstream processes. The model also shows that the rate at which costs are accumulated during a downtime event increased with the event length. This makes costing downtime difficult as the rate of cost accumulation is proportional to the length of downtime. An equivalent concept presented within Quality Costing literature was the Taguchi Quality Loss function (Taguchi and Clausing 1990). The function approximated a quadratic relationship between the failure cost and the deviation from the expected value.

A number of the cost categories identified were considered to be determined by event duration. These costs are discussed below.

Direct Labour Direct labour is the most obvious loss during a downtime event, having notable attention in both downtime (Crumrine and Post 2006) and quality costing literature (Campanella 1990; Dale and Plunkett 1995). The direct labour costs represent the costs incurred by Post to pay for operations staff which cannot process mail because of machine downtime. Specifically with regards to the downtime activities model presented above, operators were considered to remain idle for the first ten minutes of a downtime event, and restart mail processing by hand or other MPE for longer duration events.

Indirect Labour Indirect labour costs were highlighted predominantly within downtime literature (Dunks 1998). Indirect labour relates to the labour activities undertaken in support of the mail process. For Post, such activities include supervision on the facility floor, as well as administration support operations such as production and resource scheduling at the mail centre. It was reasoned that indirect labour would be affected by a machine outage for the entire duration of the outage. This was considered to be especially the case for floor supervisors, whose attention would most likely be entirely devoted to restoring the processing capacity of the site.

Equipment hire Equipment hire costs were identified within downtime literature (Edwards, Holt et al.; Levitt 1997) as one of the most visible, direct cost of downtime. The cost was calculated from the base rate for equipment hire, either as a cost of a hired piece of equipment which had broken down, or as the cost of hiring equivalent equipment to meet capacity for the duration of the downtime event. In Post's case, it owns most of its MPE and, in the event of a downtime event, falls back onto either hand processing or legacy MPE, which require very little equipment. In this case the application of hire costs to Post was not considered appropriate.

Process Inefficiency/Non-value-added activities Inefficient process costs were mentioned in a number of forms, predominantly in quality costing literature (Gryna 1999). Of most relevance to downtime costing was the variation of process characteristics from best practice. With regards to FMOCR downtime, this can most prominently be seen in the use of legacy MPE for mail sorting during extended downtime events. Three alternative processes used for supportive operations during FMOCR downtime were identified:

- Hand sorting of mail items using the Vertical Sorting Frames,
- Use of the AEG Flats Sorting Machine, a legacy MPE maintained for use during FMOCR downtime events and during peak periods.
- Use of the Spectrum 10, a small parcels machine which can process large letters. Both SWLF and DLC maintain one Spectrum, and NMC may transport large letters to Underwood Mail Centre in the case of extended delays.

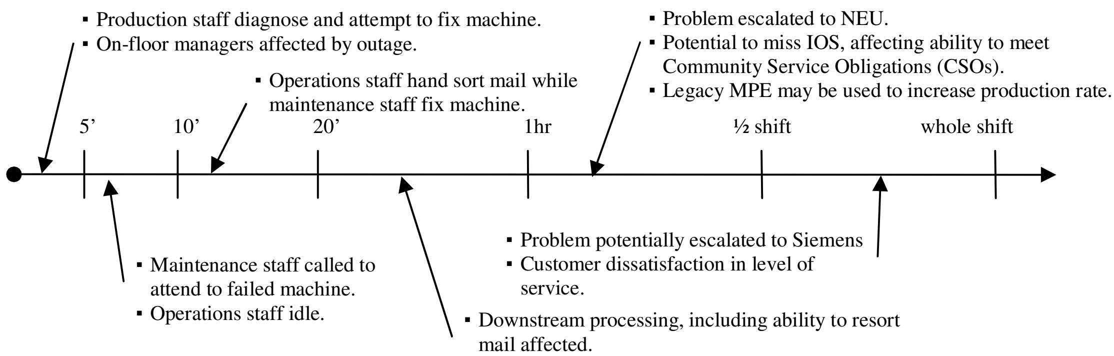

Figure 1 Effect of Downtime Duration on Process Activities

From the downtime activities model shown in Figure 1, it can be seen that the use of legacy equipment depends on the downtime event extending past ten minutes in duration. Mechanised mail sorting would likely take place for downtime durations greater than an hour. These processes are low throughput and labour intensive; the cost to the organisation of their use being twofold: the lost capacity from using lower volume equipment, and the increase in mail processing costs for the volume of mail processed.

An additional inefficient process cost outside of those listed in literature was identified for the FMOCRS. This was the use of energy resources, including both electricity and pressurised air, during downtime events.

Costs affected by Overall Downtime

Repeated downtime events were also considered more costly to the process. With each event, the costs associated with limiting the flow-on effect of the failure were greater. Although a single, short downtime event was considered unlikely to result in any significant changes to the process, several downtime events throughout the production shift would result in far more significant delays. A number of the cost categories identified in literature were considered apart of this group. These are discussed below.

Reduced Asset Life Reduced asset life was identified as an opportunity cost of continual unreliability of a machine or process (Dunks 1998). For large and complex assets, it was stated that it would be difficult to assess the long term effect of continual component replacement on the plant itself; whether or not the upkeep on the machine becomes prematurely unviable. With regards to Post's MPE, the expected life of an equipment or plant is outlined in the original business case for the equipment. However many of the current MPE used within the mail centres have outlived their expected life. To define this cost for the FMOCR, the likelihood of the machines being replaced due to persistent unreliability would need to be evaluated as the opportunity cost of the replacement valued. The likelihood of the FMOCRs being replaced prematurely was considered very low. As such this cost category was not considered in the costing analysis.

Additional Freight Charges/Priority Shipping Additional freight charges were highlighted as a cost of downtime by several authors (Levitt 1997). It was reasoned that in the case of many manufacturing industries, costs may be incurred during transport to help make up for time lost due to downtime. One of the most significant production costs for Post is transportation, which is mostly delivered by road, by a fleet of line-haul and delivery vehicles owned and operated by Post. Because of this, it is unlikely that the mode of transportation would be changed to accommodate an extended period of downtime. For local and intra-state transport, special deliveries may be run on occasions to assist in catching up lost production. However, in all but the rarest of cases, interstate delivery times would not be significantly altered for downtime events. Mail items that have not been processed by the designated loading time are left for the next truck. Because of this, it was considered that Post would rarely incur significant additional freight charges due to downtime events on the FMOCR.

Lost Opportunity Lost opportunity costs were highlighted in various forms for both Downtime (Edwards, Holt et al.; Levitt 1997; Dunks 1998; Crumrine and Post 2006) and Quality Costing (Dale and Plunkett 1995; Gryna 1999). While downtime costing literature mentioned specific costs, quality costing methods noted generalised categories of lost opportunity. The Lost opportunity costs identified could be categorised into the following three broad types:

- *Lost profit costs*, including losses from substandard product, unplanned material substitutions, repeated repairs, and ineffective use of staffing resources.
- *Lost Demand*, including lost goodwill, sales opportunity or customers.
- *Lost Capacity*, including production of defective material, components or products.

Lost Profit Lost profit costs are mentioned in various ways both within downtime and quality costing programs. While, by definition, all downtime costs would reduce the profit margin of the organisation, the use of the term lost profit was constrained to those costs which directly increase the processing costs or reduce the sale price. Costs identified previously include: inefficient activity costs (Gryna 1999) (discussed previously), rework and scrap (Levitt 1997; Dunks 1998; Bell 2006; Crumrine and Post 2006), and concessions and discounting of the service (Standards Australia Committee MS/29 on Quality Control 1982; Campanella 1990; Gryna 1999).

Rework and Scrap costs were also identified as lost profit costs. While scrap was hard to apply, mail items requiring reprocessing due to machine failure were found to be commonplace. Therefore rework costs could be defined as the cost of reprocessing mail items due to machine downtime. This cost was considered to be dependent on the number of downtime events, and so has been discussed in more detail in the next subsection.

Concessions or discounting costs were defined as the difference in sales value arising from the under-selling of poor quality goods or services. This was considered highly unlikely given the nature of Post's business.

Lost Demand Lost demand costs were the second cause of lost opportunity. Lost demand considers the financial consequences of lost customers or reputation within the community because of the inability of the process to achieve the desired output. The primary way downtime can contribute to demand loss is by delaying the delivery of mail items, causing some customers to seek alternative postal delivery services. Lost demand costs include goodwill and reputation loss, cancelled contracts, and customer dissatisfaction. Also included are the costs arising from potentially missing Internal Operating Standards or external benchmarks such as Community Service Obligations. These costs value the risk of losing customers due to machine downtime. Although it was anticipated that the cost of lost demand would be significant to the organisation, these costs were especially difficult to quantify for two reasons:

- Many of the services offered by Post, including the large letters process, have either a government enforced or market enforced monopoly, and

- Lost demand costs can be incurred anywhere along the supply chain, not just within the Mail Centres, and may even affect other processes services offered by Post. Delays within the network, including collection, transport and delivery may result in the same lost demand costs as downtime.

Post does not have any reliable methodology or data available for defining the cost of lost demand. Consultation with the accounting function of Post proved that approximations derived through any analysis were considered to be grossly inaccurate. Such figures only served to reduce the credibility of the analysis, and limited acceptance throughout the organisation. For this reason costs associated with lost demand were not included in the final analysis.

Lost Capacity Lost capacity was the most obvious lost opportunity cost, and can be valued by the effect that machine downtime has on the ability to supply the product or service offered. With respect to the FMOCR, lost capacity is the inability to value-add to the organisation during a downtime event. For an understanding of this cost, it was necessary to model the activities during an operational shift. The model was generalised to accommodate variances in scheduling approaches between the sites. The basic assumption was that any lost production time would have to be caught up at the end of the shift. It was also assumed that the catch up time would be resourced by a combination of remaining operational shift time, and operational overtime. For very large volumes of downtime, mail may not be able to be processed before delivery deadlines, in which case the residual mail would be processed during the next operational shift. The scenarios presented are shown in
Figure 2.

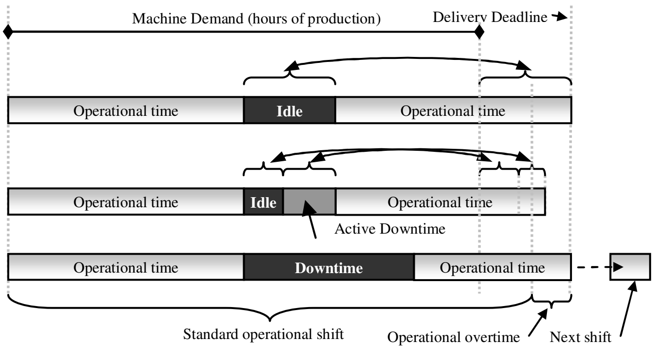

Figure 2 Generic Lost Capacity Model

It should be noted that for some operational periods, downtime does not reduce the volume of mail processed. The supply of large letters on a daily basis is considered finite; the reduction of downtime on the FMOCR cannot in itself increase the volume of mail items processed. This has lead to mail centres arguing that there are no lost capacity costs resulting from machine downtime, reducing the perceived need to minimise downtime wherever possible.

It was proposed that lost capacity for the FMOCR could be determined by considering the value of additional processes that could have used the available machine time. Several activities were identified that could use this time, which were prioritised by their benefit to the organisation. The activities identified were:

1) Processing of any mail that otherwise would be left as residual for the next operational shift (part of lost demand costs)
2) Re-processing and round sorting mail that otherwise would require manual processing at delivery centres,
3) Any combination of the following cost reduction or value-adding activities, including:
   a) Reduction in volume of overtime paid,
   b) Processing of competition mail or other mail sourcing opportunities, or
   c) Reduction of machine capacity.

In the initial business case for the FMOCRs, one of the primary savings to the organisation was the reduction of full time equivalent (FTE) labour at local delivery centres. This was because the FMOCR was anticipated to be able to round sort mail before being transported, requiring less manual sorting at the delivery centres. The inability to realise these projected savings is one of the most determinable costs of lost capacity.

Downstream processing costs/Process bottlenecking Process bottleneck costs were described within downtime costing literature (Gryna 1999) as the costs associated with the starvation of downstream processes. In effect, these costs describe the lost opportunity of the downstream processes. This includes both interstate mail centres and delivery centres. Using the lost opportunity model in
Figure 2, it was proposed that extended delays are most likely to affect the volume of residual mail. Since it was acknowledged that only in rare circumstances would transport be delayed, this mail would either remain at the mail centre until the next load was sent, or a special late delivery would be made in extraordinary circumstances such as an extended power outage.

Because of this, it was considered unlikely that downstream processes would suffer significant costs in the event of an extended downtime period. In the most extreme cases, a special delivery would be made at additional cost to Post.

Customer dissatisfaction/Complaints handling Customer complaints handling was highlighted as a cost of poor quality (Gryna 1999), borne out of a need to communicate with dissatisfied customers due to the deliverance of a below standard product or service. Post operates multipurpose customer communications services within each state, one function of which is the handling of complaints and enquiries. Assuming that the primary reason for delayed mail items was downtime, the customer complaints handling cost was defined as the proportion of the communications centres labour costs associated with handling the enquiries and complaints from delayed large letters.

Liability and penalties Liability and penalty costs were a concern of both quality (Standards Australia Committee MS/29 on Quality Control 1982; Campanella 1990; Gryna 1999) and downtime (Levitt 1997) costing methods. This category of cost related to customer imposed penalties, either for late delivery, or delivery of poor quality goods or services. In the case of Post, it was considered unlikely that customers would impose penalties for delayed delivery of mail items. However it was acknowledged that failure to meet the community service obligations (CSOs) could result in government imposed penalties, which may or may be intangible. Failure to meet the CSOs would also result in bonuses not being awarded to staff, affecting the working environment and employee satisfaction. The cost of this has not quantified, however would most likely result in an indirect increase in labour cost over the long term.

Per Event Downtime Costs

A number of costs were identified as not being directly related to either downtime length or volume, but were considered to exist either due to the frequency of downtime events, or as a flow on effect of individual events. Such costs as spares procurement were considered to be incurred irrespective of the volume of downtime. Instead, this cost could be determined from costs arising from individual downtime events. Such cost categories are discussed below.

Rework and Scrap Rework and scrap were highlighted as product related costs in both quality (Campanella 1990; Dale and Plunkett 1995) and downtime (Levitt 1997; Dunks 1998; Bell 2006; Crumrine and Post 2006) costing methods. With regards to downtime, scrap and rework maybe generated in a process environment where the product is compromised by the stoppage. Damage may occur either in the lead up to the event, or in the start up process immediately after. While scrap is unlikely to be created during mail processing, rework maybe generated in the event of a downtime event causing the FMOCR to reject mail items. The cost of rework was valued by examining the lost opportunity cost for the duration of time to reprocess the mail items.

Tooling for rework Tooling costs were not easily identified within the mail processing. However rework does have additional flow on effects to the machine. One possible effect identified was an increase in maintenance activities due to the increased mail volume. However, in the case of the FMOCR, the volume of reworked mail was considered insignificant in respect to the total mail volume processed, and therefore would not significantly affect maintenance decisions.

Process improvement Process improvement costs were identified within quality costing methods as costs arising from process improvement activities designed to reduce non-conformance. Process improvement costs were also described as failure analysis and process redesign costs (Gryna 1999). With relation to downtime costing on the FMOCR, process improvement costs were identified as costs arising from programs undertaken to minimise downtime on the machine.

In addition, a number of programs were identified which influence the amount of downtime that a machine may suffer, however these were not costed because the primary aim of the programs was not downtime reduction. Many of these programs aimed to affect other aspects of the operations and maintenance of the FMOCRs, with downtime reduction one of the anticipated results.

Spares procurement The additional cost of procuring spares for repairs during downtime events was highlighted by downtime costing literature (Dunks 1998). The costs of spares procurement covered two critical areas: higher spares purchasing cost, and higher spares freight cost. Spares procurement costs were considered to be independent of either downtime length or total downtime volume, but rather could be costed against individual events.

Post specifies a minimum stock level to be maintained at each site in order to maintain satisfactory downtime responsiveness. In order to maintain this satisfaction level, regular downtime events where parts are replaced increases the volume of spares that have to be stored on site. This increased volume of spares has additional costs, including the lost opportunity of the capital invested, and the floor space used for storage. An Inventory Carrying Cost of 21.2% was described as the burden of stored inventory levels as a percentage of the capital cost of the item. By identifying the value of materials stored on-site for downtime events, an annual cost from this storage can be calculated.

The second area where spares purchasing may be affected by downtime is in spares transport. Additions supplies are occasionally required in order to restore machine state. In these cases, spares are required to be transported from NCS to the mail centre. This is generally air freighted from Melbourne to the mail centre, at significant cost to the network. In order to determine the cost of these emergency freight activities for the FMOCR, the cost of specific events was determined from flight logs recorded by National Central Stores.

Lost or Missing Information Costs Lost or missing information costs were highlighted as apart of quality costing techniques. However, the involvement of downtime was not considered likely to increase the costs associated with lost paperwork or other information. Therefore these costs were considered to be irrelevant to downtime costing.

THE TOTAL COST OF DOWNTIME

The above mentioned costs were valued using available data sources within Post over the period August 2005 – 2006. The data was extracted from financial, Human Resources, production and maintenance data sets. As can be seen in Table 1, the total cost of downtime for the FMOCR, averaged across all sites, was valued at 5.0% of the asset replacement value. For operational use, downtime was determined to be worth $138 per run-hour per machine, or $817 per hour of accumulated downtime. However it was conceded that, due to the nature of cost accrual during downtime events, this figure more accurately represented the cost of downtime for events close to the FMOCR's MTTR.

Table 1 Total Cost of Downtime

Cost Title	Cost Description	% of Total Downtime Cost
Idle Production Labour	Labour costs associated with idle operators during downtime	19%
Direct Maintenance Labour	Labour costs associated with reactive maintenance during operational periods	14%
Management/Staffing Costs	Management Labour costs associated with FMOCR lost during downtime periods	2%

Cost Title	Cost Description	% of Total Downtime Cost
Customer Complaints Handling	Labour cost of handling customer enquiries about delivery delays	1%
Increased Spares Storage	Cost of having to store increased spares level due to unscheduled downtime	0%
Spares Procurement and transport	Extra freight burden to transport emergency spares because of machine unavailability	1%
Reduced Roundsort Capacity	Possible downstream labour savings lost due to DT	55%
Extraordinary consulting costs - Siemens Serivce Contract	The current cost due to downtime	5%
Extraordinary consulting costs - FMOCR health check	NEU performed health check program for all FMOCR's - once per year	1%
Extraordinary consulting costs - Siemens Site Visits	The cost for a Siemens Engineer to come out on site. Assume 6 times/year	0%
Energy Costs	Cost of energy used during DT	0%
Total Cost of Downtime as a % of Asset Replacement Value		**5.0%**

CONCLUSION

This paper has outlined the development and valuation of a cost of downtime model for the FMOCR. The outcome of which has been both the methodology for determining downtime on the FMOCR, as well as the actual cost of downtime. In doing so, this paper has addressed two key failures of the current state of knowledge, being: the definition of key costs of downtime and how they relate to a manufacturing environment, and a methodology for how these costs should be valued for a specific process. Using available literature on downtime and quality costing, this paper has provided a defined and defendable cost of downtime for the FMOCR which is representative of real costs within the organisation.

The downtime cost analysis found that the single greatest cost of downtime for the FMOCR was lost capacity. This was valued by examining the lost ability to round sort mail, as specified in the original business case. The overall value of FMOCR downtime to the network was found to be 5.0% of the FMOCR's asset replacement value. This was equivalent to $138 per operational hour.

This paper has addressed the current knowledge gap by providing a methodology for identifying and valuing downtime related costs, with the specific application of costing downtime on Post's eight FMOCRs. In doing so, this research has presented one of the very few methodologies available for costing downtime, and one of the most comprehensive assessments of the total cost of downtime of a plant or equipment. The work within this paper has also incorporated quality costing principles to provide a stronger theoretical framework. Although the results may not be able to be directly transferable to other industries, the method presented in here is applicable to any manufacturing environment which would benefit from a more complete understanding of the magnitude of the cost of machine or process downtime.

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