ESTIMATION OF COST OF DOWNTIME OF INDUSTRIAL PROCESSES DUE TO VOLTAGE SAGS

Sarat Chandra VEGUNTA
TNEI Services Ltd – UK
chandra.vegunta@tnei.co.uk

Jovica V MILANIOVIĆ
The University of Manchester – UK
milanovic@manchester.ac.uk

ABSTRACT

The paper describes a methodology for estimation the Cost Of Downtime (COD) of industrial processes due to Power Quality (PQ) disturbances. The developed methodology is based on the experience gained during the cost of downtime estimation study conducted on a typical pharmaceutical aseptic manufacturing process. Microsoft Excel is used for user data entry, manipulation and results presentation.

INTRODUCTION

The paper presents a comprehensive post process failure Cost of Downtime (COD) estimation tool that can estimate COD profile for fault incident variation with time of the day. This tool builds on the work reported in [1] and experience gained through discussions with pharmaceutical manufacturing plant personnel. Proposed COD estimation tool, is strictly applicable to aseptic manufacturing processes, however, general principles of the developed methodology are applicable to any continuous manufacturing process.

All relevant associated cost components are included in the COD estimation. The tool calculates related direct cost accrual per process activity and restart costs based on historical information and estimates COD profile variation for time of day. It also estimates online direct costs and actual restart costs and plots COD versus time of the day. Furthermore, the methodology takes into account different product variants, product amount variation with time, active processes, single or multiple batches, simultaneous operation of batches and failure scenarios at each process activity.

GENERAL ASSUMPTIONS AND PROCEDURES

The proposed cost of downtime (COD) estimation model is based on the following assumptions:

j \ i	P_1	P_2	P_3	P_4	P_5
F_1	x	x	x	x	x
F_2		x	x		
F_3		x			
F_4		x			

Figure 1 Process activity and associated likely failure scenarios matrix.

1) Let 'n' be the total number of process activities in the manufacturing process. Let 'i' be the process activity index/pointer that points to 'n' processes involved in a manufacturing process, i.e. $i = 1,2,\ldots,n$. Figure.1 illustrates this using an example manufacturing process. There are 5 (i.e. n=5) processes indicated by the pointer 'i'.

2) It is very common to find different variants of the same product, (e.g. a pharmaceutical drug with different dosages, metal cutting of different sizes, etc.) which all use or include the some additional process activities. Let there be 'y' number of product variants using the same manufacturing production line or involving additional process activities. Let 'u' be the pointer pointing to each product variant of 'y'. All additional process activities are included in 'n'.

3) Let 'm' denote the likely number of process disruptions in a process activity. The maximum value of 'm' is chosen based on a particular process activity which has the largest number of maximum process disruptions. Let 'j' be the process failure index which points to likely failure scenarios in each process activity, i.e. $j = 1,2,\ldots,m$. Figure.1 illustrates this using an example manufacturing process. In this example each process activity has corresponding failure scenarios indicated by 'x'. Thus process activity P_1 has 1 failure scenario, P_2 has 4 failure scenarios etc. Here, $m = 4$, i.e., the maximum number of failures seen by any process activity (P_2 in this case it). If for a particular process activity *j*, the maximum number of failure scenarios (m_j) is less than maximum number of failure scenarios in all process activities (m), then the restart cost associated with ($m - m_j$) failure scenarios is assigned value zero.

4) The amount of product handled at each activity is constant.

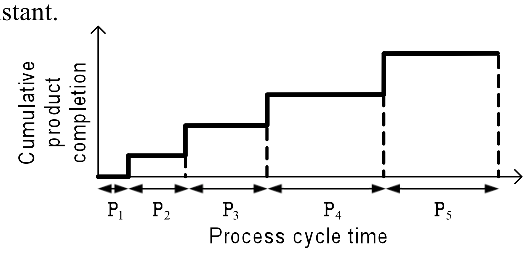
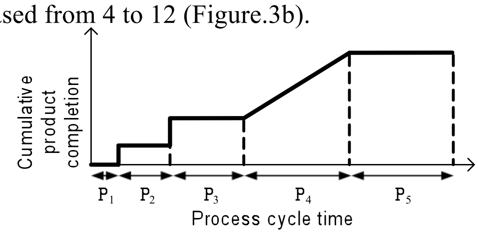


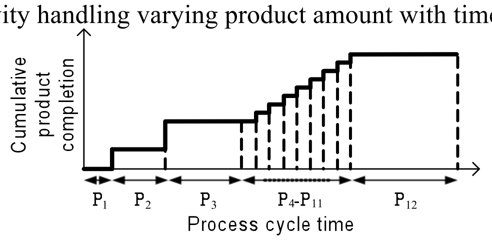
Figure 2 Example manufacturing process.

5) If the amount of product handled in a particular process activity varies with time, then that process activity is sub-divided into a number of process activities such that at each new process activity the amount of products handled does not vary with time. All new process activities which are a

result of sub-division, should also be included in 'n'. This is illustrated in Figure.3 using a manufacturing process with five process activities. All process activities except P_4 (in Figure.1a) have a constant amount of products handled with time. P_4 is therefore sub-divided into eight new processes such that the amount of product handled by each new process activity is constant. The number 'n' as a result increased from 4 to 12 (Figure.3b).



a. Example of manufacturing process with a process activity handling varying product amount with time.



b. New process activities as a result of process activity sub-division.

Figure 3 Example illustrating process activity sub-division for a process activity handling varying product amount with time.

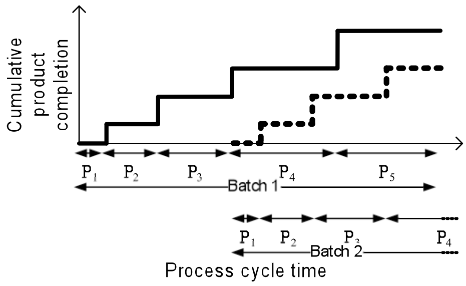


Figure 4 Example manufacturing process with simultaneous batches being processed.

6) Two or more batches that start at different instances may overlap. The COD calculated will thus depend on the instance of process failure occurrence and on the number of batches overlapping at that instant. Batch overlapping for two batches is illustrated in Figure.4. Batch 1 is shown using a thick solid line while Batch 2 is shown using thick dashed line.

7) Parallel (simultaneous) batch processes can be aggregated into a single batch. The failure cost however, will account only for the lost batch(es). Parallel batch processes are considered as a product variant and included in 'y'.

Calculation of Direct Cost Component

The following are the cost component calculations for n process activities, selected j^{th} failure and u^{th} product variant processed at each i^{th} process activity.

ph_{ui} → Amount of product handled in % at i^{th} process.

r_{ui} → Cumulative raw material cost in £ at i^{th} process.

os_{ui} → Outage savings accrued for product handled in £ at i^{th} process, following a complete/partial process disruption.

e_{ui} → Cumulative energy cost in £ at i^{th} process.

l_{ui} → Cumulative labour cost in £ at i^{th} process.

o_{ui} → Cumulative overhead cost in £ at i^{th} process.

pr_{ui} → Profits lost for product handled in £ at i^{th} process, following a complete/partial process disruption.

pe_{ui} → Penalties accrued for product handled in £ at i^{th} process.

prm_{ui} → Progressive raw material cost in £ at i^{th} process ($ph_{ui} \times r_{ui}$).

s_{ui} → Progressive outage savings accrued for product handled in £ at i^{th} process, following a complete/partial process disruption.

pec_{ui} → Progressive energy cost in £ at i^{th} process ($ph_{ui} \times e_{ui}$).

plc_{ui} → Progressive labour cost in £ at i^{th} process ($ph_{ui} \times l_{ui}$).

poc_{ui} → Progressive overhead cost in £ at i^{th} process ($ph_{ui} \times o_{ui}$).

ppl_{ui} → Progressive profits lost for product handled in £ at i^{th} process, following a complete/partial process disruption ($ph_{ui} \times pr_{ui}$).

ppa_{ui} → Progressive penalties accrued for product handled in £ at i^{th} process ($ph_{ui} \times pe_{ui}$).

Direct cost in £ at i^{th} process is given as,

$$dc_{ui} = ph_{ui}\left(r_{ui} + e_{ui} + l_{ui} + o_{ui} + pr_{ui} + pe_{ui}\right) - s_{ui} \quad (1)$$

Total direct cost is given as,

$$TDC = \sum_{u=1}^{y}\sum_{i=1}^{n} dc_{ui} \quad (2)$$

Calculation of Restart Cost Component

eda_{uij} → Expert damage assessment cost in £ for j^{th} failure at i^{th} process activity.

$ldrr_{uij}$ → Lost (lo), damage (da), repair (re) and replace (rp) of parts, production material etc, for j^{th} failure at i^{th} process activity, in £ ($lo_{uij} + da_{uij} + re_{uij} + rp_{uij}$).

en_{uij} → Energy cost in £ consumed from instance of failure to restart for j^{th} failure at i^{th} process activity.

rlc_{uij} → Idle labour cost (il), restart labour cost (rl), labour overtime to recover at later date (rlo) in £ for j^{th} failure at i^{th} process activity ($il_{uij} + rl_{uij} + rlo_{uij}$).

Cost of restart for j^{th} failure at i^{th} process activity is given,

$$rc_{uij} = eda_{uij} + ldrr_{uij} + en_{uij} + rlc_{uij} \tag{3}$$

Total restart cost at any given instance for j^{th} failure selected/assessed at each i^{th} process activity is given,

$$TRC = \sum_{u=1}^{y}\sum_{j=1}^{m}\sum_{i=1}^{n} rc_{uij} \tag{4}$$

~~Hidden Cost Factor Calculation~~

rct_{uij} → Retained competitiveness in p.u. from nominal as result lost of product due to j^{th} failure at i^{th} process activity.

rrt_{uij} → Retained reputation in p.u. from nominal as result lost of product due to j^{th} failure at i^{th} process activity.

rcs_{uij} → Retained customer satisfaction in p.u. from nominal as result lost of product due to j^{th} failure at i^{th} process activity.

ret_{uij} → Retained employee tolerance in p.u. from nominal as result lost of product due to j^{th} failure at i^{th} process activity.

Hidden cost factor for j^{th} failure at i^{th} process activity is given,

$$hcf_{uij} = rct_{uij} \times rrt_{uij} \times rcs_{uij} \times ret_{uij} \tag{5}$$

Total hidden cost factor at any give failure instance is given,

$$HCF = \prod_{u=1}^{y}\prod_{j=1}^{m}\prod_{i=1}^{n} hcf_{uij} \tag{6}$$

~~Total Cost of Downtime~~

Total Identifiable Downtime Cost (TIDC) at a given instance of failure is given as,

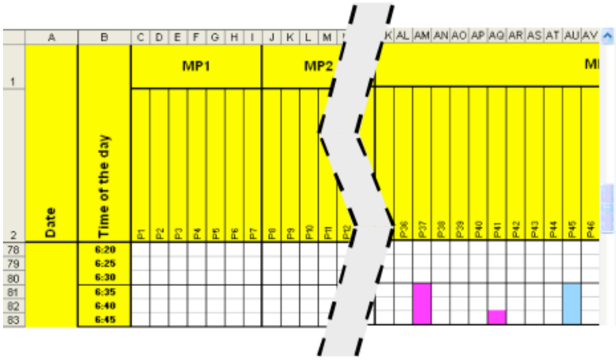
$$TIDC = TDC + TRC \tag{7}$$

At any given instance of failure that leads to process disruption the total COD is a function of TIDC and HCF, i.e.,

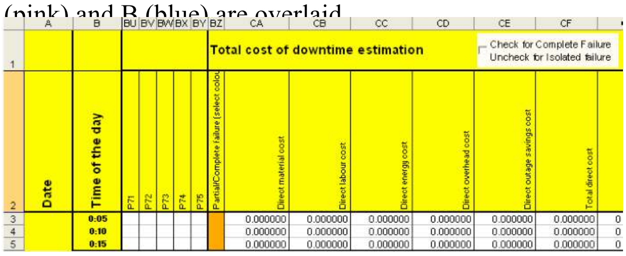
$$COD = TIDC + HCF \tag{8}$$

COD ESTIMATION PROCEDURE

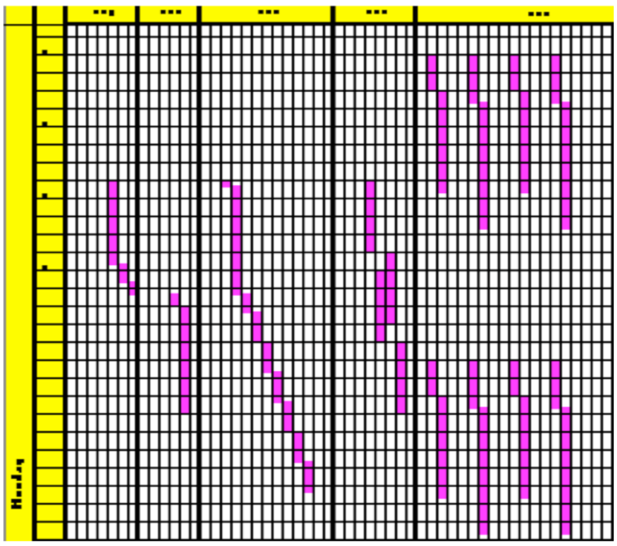
The step-by-step procedure to estimate the COD for a single failure or to establish the COD profile for future COD estimates is as follows:



a. Part of work schedule interface showing typical day process activity. Work schedules for product variant A (pink) and B (blue) are overlaid.



b. Part of cost of downtime result spreadsheet, along with option to select isolated or complete process disruption.



c. Compressed (a. and b. together) view of work schedule worksheet illustrating a layout of a typical day's work schedule.

Fig. 5 Graphical user interface of COD estimation tool.

Step 1: Based on the assumptions specified in second section of this paper, evaluate the total number of product variants (y), the total number of process activities at any given instant (n) and maximum number of potential failures among all process activities (m). Assign, $i = 1,2,\ldots,n$, $j = 1,2,\ldots,m$ and $u = 1,2,\ldots,y$;

Step 2: For each u^{th} product variant, determine the associated progressive direct cost component for each process activity 'i'. Determine the restart cost components for each j^{th} failure scenario (this should include the cost associated for a complete failure at that process) for selected i^{th} process activity. (*Note:* If for a particular i^{th} process activity the maximum number of failure scenarios (m_j) is less than maximum number of failure scenarios in all process activities (m), then the restart cost associated with ($m - m_j$) failure scenarios assumes zero value.) Establish an employee annoyance level (retained employee tolerance, 1 – employee annoyance) for each j^{th} failure instance of i^{th} process activity. Establish customer satisfaction and reputation retained level for instance of non-delivery of a product variant in time;

Step 3: Prepare a work schedule highlighting the active process activities for a typical day for which COD profile has to be established. This work schedule should include active process activates for various product variants and their simultaneous processing at any given time;

Step 4: Establish $TIDC$ and HCF for designed work schedule based on calculations specified in previous sections for selected failure instances at each active process activity. Calculate COD as $TIDC + HCF$.

CASE STUDY

The developed methodology is implemented on a typical pharmaceutical manufacturing process that has two product variants (*y=2*), six major processes (*n=6*) that further subdivide into total of 75 sub-processes. Direct cost accrual per process activity, that the product accrues as it moves in the production line and restart cost estimates (based on hit rate and pass rate) are obtained from plant's finance department. The COD estimation tool is developed in Microsoft Excel and includes worksheets to enter required financial data and a typical day work schedule. The work schedule worksheet contains process activity – time of day cell-plane, with process activities represented in columns (0-75 from left to right) and time of day (6:00-21:30 hours) in rows. The user selects the work schedule by highlighting corresponding active process activities with corresponding activity time using appropriate colors (each color corresponds to product variant or type of process failure: partial or complete).
Figure.5 shows the Microsoft Excel based COD estimation graphical user interface (GUI). Figure.6 shows breakdown of generated normalized COD profile for a typical work schedule (Figure.5c) during the day.

CONCLUSIONS

The proposed methodology and developed tool gives opportunity to industrial customers to generate COD profile as a function of time of day (inclusive of sag performance variation at the point of common coupling) and to develop detailed cost breakdown structure. This can facilitate more informed decision making regarding plant exposure to PQ disturbances and required mitigation measures. The COD estimation procedure proposed here is not limited to the industrial sector only. It can be equally well used by commercial, services and other sectors to facilitate uniform COD data collection and processing. The common approach to COD estimation would lead to more accurate estimation of financial consequences of PQ disturbances to society at large.

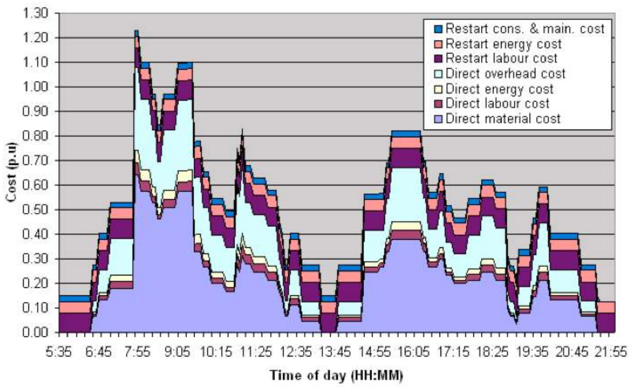


Figure 5 Part of the COD profile for the example manufacturing process with simultaneous batches being processed

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REFERENCES

[1] "Power Quality: Customer Financial Impact/Risk Assessment Tool," BC Hydro, A04-587b, 2005.

Sarat C. Vegunta received his Ph.D from The University of Manchester, and is currently working as a Technical Consultant at TNEI Services Ltd, Manchester, UK.

Jovica V. Milanović is a Professor of Electrical Power Engineering and Deputy Head of School (Research) of Electrical and Electronic Engineering, The University of Manchester (formerly UMIST), Manchester, U.K.