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SCOPE & TOPICS

Advances in Production Engineering & Management (APEM) is an interdisciplinary refereed academic journal. The main goal of the APEM is to present high quality research developments in all areas of production engineering and production management, as well as their applications in industry and services, to a broad audience of academics and practitioners. In order to bridge the gap between theory and practice, applications and case studies are particularly welcome. For theoretical papers, their originality and research contributions are the main factors in the evaluation process. Fields of interest include, but are not limited to:

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- Decision Support Systems
- Discrete Systems and Methodology
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- Production Processes
- Project Management
- Rapid Prototyping
- Robotics and Manipulators
- Quality Management
- Queuing Systems
- Risk and Uncertainty
- Self-Organizing Systems
- Simulation
- Statistical Methods
- Supply Chain Management
- Technology, Technological Improvement
- Virtual Reality
- Visualisation

General approaches, formalisms, algorithms, or techniques should be illustrated with significant applications that demonstrate their applicability to real-world problems.

EDITORIAL

Welcome to the new issue of the Advances in Production Engineering & Management (APEM), ISSN 1854-6250. The mission of the APEM is to serve as a non-profit platform for publishing of scientific and professional articles and other useful resources (practical information, book reviews, equipment and software reviews etc.). Production engineering and production management are branches that concern the development, improvement, implementation and evaluation of integrated systems of people, knowledge, equipment, energy, material and process. They draw upon the principles and methods of engineering analysis and synthesis, as well as mathematical, physical and social sciences together with the principles and methods of engineering analysis and design to specify, predict and evaluate the results to be obtained from such systems. Whereas most engineering disciplines apply skills to very specific areas, production engineering & management can be applied in virtually every industry or in services.

We welcome contributions for the publication of research work in academic institutions, in industry, in services or in consultancy. The editors of the APEM are searching primarily for original, high-quality, theoretical and application-oriented research papers (based on theory development, practical experience, case study situations or experimental results).

Till now research papers from the field of manufacturing, machining and production management were published. We are planning to publish also special issues, dedicated to Layered technology, Internet based Manufacturing, Assessment management and more.

Editor-In-Chief
SIMULATION OF GRID COMPUTING WORKLOAD MANAGEMENT USING WEIGHTED RANDOM MATCHING

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Abstract:
This paper presents the simulation results of a novel Grid computing workload management scheme based on job-pull operational mode and weighted random matching. Large scale Grid computing system as one used in the CERN-ALICE experiment has been successfully modelled and simulated using discrete-event simulation technique. The efficiency of the proposed scheme has been demonstrated by using the workload resembling the processing of high throughput computing tasks of the CERN-ALICE experiment. To generate more realistic synthetic workload the model with user-oriented workload generation has been used. The simulation results showed that the proposed scheme enables efficient intracommunity workload, giving each user weighted fair access to computing resources. Therefore the applied stochastic matching enables implementation of the computational economy for the workload management scheme with job-pull operational mode. However, the presented results are limited on large scale computing systems and workloads that consist of uniform and independent jobs.

Key Words: Grid Computing, Grid Resource Broker, Grid Workload Management, Discrete-Event Simulation

1. INTRODUCTION

Workload management system (WMS) is a software service responsible for distributing and managing tasks across computing and storage resources available on a Grid. In the High Energy Physics domain, especially for the CERN LHC experiments, the specific WMS (Dirac [1] for LHCb experiment, AliEn [2], [3] for ALICE experiment) are based on the pull operational mode [4] using job agents.

Whenever there are free computing resources available, Computing Element (CE) that is an interface to a computing cluster or other Grid pulls matched job agents created on behalf of submitted user jobs. Job agents are deployed on the computing slots (CS) as regular jobs. Once started on the CS, they prepare execution environment and then pull and execute real user jobs. The main advantage of the job pull approach is a natural load balancing of the computing resources.

On the other hand, WMS has to give each user access to resources according to the priority assigned with the user account and finally to allow resource allocation that is drivable by computational economy [5]. For the task of intracommunity workload management AliEn and Dirac meta-schedulers currently use first-come, first-served (FCFS) based service policy with periodic task queue reordering depending on queue states, job load and resources availability.

However, resource pooling for large scale systems (order of 104 computing nodes) very often shows burst nature that is usually caused by finishing or cancelation of large jobs or starting of computing cluster. It could result that temporary high ranked tasks receive almost all free resources while other tasks could be in a starvation until next reordering cycle. Moreover, the frequency of reordering cycle is limited by potentially very long job queue.
To overcome presented problems, in the case for a distributed parallel analysis in CERN-ALICE experiment [6] performed on a very large grid scale system, a workload management scheme using weighted random (WR) matching applied to the job pull operational mode is proposed in this paper. This scheme presumes that user tasks can be split into independent jobs and it could be applied to distributed parallel analysis in ALICE experiment.

Stochastic workflow scheduling in large scale computing environments has been already proposed by [7]. As far as we know, no previous work has proposed the idea and simulation results of using random weighted matching for meta-scheduler architecture with job pull operation mode.

2. AGENT BASED JOB PULL MODEL

AliEn [8] (ALICE Environment) is a workload managements system used in ALICE experiment. This section presents the specific resource brokering architecture used in AliEn and which is simulated using DE simulator. Figure 1 shows the diagram of the described architecture.

A user application can submit a compound task that can be split into a discrete number of independent jobs. A nominal priority is assigned to each user and it can be held constant or regularly updated according to grid economics parameters (i.e. user account balance). Instead of managing potentially large number of jobs, resource broker (RB) manages agent table (AT). If a job submitted to central job queue (JQ) has a unique key (combination of user ID and job requirements), a new related AT record is created. If there is a key match, only the job counter is incremented for the matched AT record. As a result every job in JQ has a related record in the AT table.

![Architecture of Agent based pull model with WRM.](image)

Local computational resources available at every site are managed by a Computing Element service (CE). CE monitors underlying computing resources queuing system and if there are
any free computing slots, agents from CE’s local bounded agent queue (AQ) are submitted to them. Concurrently, CE tries to keep its AQ queue full and periodically demands agents from RB. RB picks AT records for matching according to implemented matching selection policy and the list of matched agents is then sent to CE. Finally, every running agent pulls and executes related jobs from JQ using FCFS service policy. The agent terminates if there are no related jobs in the JQ. If the WR matching selection policy is applied, the probability of an AT record selection and subsequent agent creation is proportional to the temporary assigned user priority weight.

Therefore a job priority is primary determined with the matching order. The running agent that pulls related jobs from the JQ (FCFS) defines the second level of prioritization. The presented prioritization algorithm does not involve any sorting operations on the potentially long JQ.

3. WEIGHTED RANDOM MATCHING

The selection of AT records for matching is performed using WR selection. The complete process is divided into two following steps:

3.1 AT record priority-weight (pwAn) calculation

For a $i$th $i = 1, ..., N_A$ AT record created by user $j$ $j = 1, ..., N_U$ we define a priority-weight $pw_{Ai}$. The value of $pw_{Ai}$ is calculated at the time when new AT record is created as follows:

$$pw_{Ai} = nom_{Uj} \cdot price_{Ai} \quad (1)$$

where: $nom_{Uj}$ is nominal priority for user $j$ ($nom_{Uj} > 0$), $price_{Ai}$ is job execution price offered by user ($price_{Ai} > 0$).

3.2 AT selection/matching

Random selection of an AT record for matching, is not performed uniformly by RB, instead it uses a given weight for each AT record. Probability that $s$th agent record that belongs to user $j$ is going to be selected is:

$$p(A_s) = \frac{pw_{As}}{\sum_{n_{AUj}}{pw_{Ai}}} \quad (2)$$

where: $pw_{As}$ is agent record priority and $n_{AUj}$ is temporary number of agent records in AQ created on behalf of user $U_j$.

Selected AT record is then set ineligible for subsequent matching selections. After that RB matches selected AT record job requirements and CE capabilities. If there is a match, RB creates new agents for sending to CE. If the number of created agents for is still lower than a number requested by CE and there are eligible AT records, a new AT record selection/matching tour is performed.

4. SIMULATION SETUP

The proposed scheme is evaluated by custom made discrete event (DE) simulator described in [9]. It utilises optimized Ptolemy C++ DE library [10] to simulate components and communication used in the real system.

Instead of bottom-up, top-down simulation modelling is used. The system model focus was not on the system components but on the job and data workflow. The communication of system components is modelled separately (message dispatcher component) from file
transfer simulation. Finally, the simulation model has the identical job and data workflow as the real system and comparable performance of processing elements. Figure 2 presents the structure and message paths of DE components.

Figures 2: DE Components and message paths.

4.1 CE parameters

CE requests agents every 60s. Simulated system consists of 10 CE with parameters defined in the Table I.

<table>
<thead>
<tr>
<th></th>
<th>CE1</th>
<th>CE2</th>
<th>CE3</th>
<th>CE4</th>
<th>CE5</th>
<th>CE6</th>
<th>CE7</th>
<th>CE8</th>
<th>CE9</th>
<th>CE10</th>
<th>Total</th>
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<tbody>
<tr>
<td>nSlots</td>
<td>300</td>
<td>600</td>
<td>900</td>
<td>1200</td>
<td>1500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9000</td>
<td>9000</td>
</tr>
<tr>
<td>maxAQ</td>
<td>15</td>
<td>30</td>
<td>45</td>
<td>60</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

where: nSlots is number of computing slots, and maxAQ is a maximal number of allowed agents waiting in the bounded AQ (5% percent of available computing slots). Computing slots delivers random performance uniformly distributed in the interval (1-1.5) kSi2k. Every CE is capable to execute any type of job (uniform jobs).

4.2 Simulation workload

A comprehensive statistical analysis of workloads collected on data-intensive clusters and grids presented in [12] shows a strong correlation of user behaviour (job submission) and a previous job processing history. To generate more realistic synthetic simulation workloads we have used a user-oriented workload generation. Every user is modelled as separate simulation unit that submits jobs dependent on its previous job processing history.

As it is common for ALICE data processing, one low priority (LP) user submitting large batch of jobs with high processing requirements was used. LP user jobs are accepted in the JQ only when the size of JQ is below some predetermined trigger size (minQT=100). Job agent is set to execute only one LP job until termination. In our simulation cases LP user starts submitting jobs at tS=0s (real time=20:00h, overnight background jobs).

The submissions start for every normal priority (NP) user is placed uniformly random in the interval tS=43200-46800s (real time=8:00-9:00h of the next day). NP user submits new job 180s after its previously submitted job is finished. Job submission for all users stops at tS=79200s (real time=18:00h).
Table II presents the jobs/users workload parameters. NP users are divided into 3 size groups according their job computing requirements: small (S), medium (M), and large (L). To simplify results analysis, jobs of every size group have equal processing requirements. It is assumed that all job data input/output operations are performed from local storage elements and therefore data transfer time is included into job processing requirements. Further, every size group is divided into 5 equal price subgroups according to user job offer prices. Every price subgroup consists of 5 users.

Table II: jobs/users parameters.

<table>
<thead>
<tr>
<th>Job type</th>
<th>Num. of users</th>
<th>price</th>
<th>nSubJob</th>
<th>( P[kS12ks] ) (min,max)</th>
<th>nomUj</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP</td>
<td>1</td>
<td>1</td>
<td>500</td>
<td>3600,7200</td>
<td>1</td>
</tr>
<tr>
<td>S</td>
<td>5</td>
<td>1</td>
<td>100</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>5</td>
<td>1</td>
<td>200</td>
<td>1200</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.5</td>
<td></td>
<td></td>
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<td></td>
<td>5</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>5</td>
<td>1</td>
<td>400</td>
<td>2400</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3 shows number of jobs in JQ for one of the simulation runs using the previously described workload generation. At the start of NP user activity, almost all computing resources are occupied with LP jobs.

Figure 3: Number of jobs in JQ.
The resources released by finished LP jobs are gradually shifted to NP jobs (see Figure 4). It could be also seen at Figure 4 that the overall system efficiency (*running jobs/total slots*) is lower for NP jobs, which is expected because the jobs with a smaller processing requirements have as a relative larger pre-processing overhead.

5. SIMULATION RESULTS

First, the results for the simulation runs using FCFS matching with periodic priority sort as it is implemented in AliEn are presented. Then the performance metrics for random and WR matching is analysed.

5.1 Performance metrics

Grid users submit jobs with certain quality of service expectations. Arithmetic mean of turnaround times is used as the major performance metric. The arithmetic mean of turnaround time is defined as:

\[ TT_A = \frac{1}{|S|} \sum_{j \in S} tt_S \]

(3)

where: \( tt_S \) is the turnaround time of job \( j \), \( S \) is the set of jobs in the workload, and \(|S|\) is the number of jobs in the set. A lower \( TT_A \) means a better performance from an end-user perspective.

For large sequential batch jobs service delay is often acceptable, but users using applications for distributed parallel interactive data analysis, as in, expect that a fraction of jobs is started as fast as possible even under heavy occupancy of resources. Therefore for interactive applications a performance metrics \( R \) that shows progression of a user job execution is introduced. \( R \) is defined as \( n^{th} \) percentile of job partial-responses times. Partial response time measures how long a job takes from its submission to \( c\% \) completion. The 90\(^{th}\) percentile of the response time for 5\% job completion is used.

Every simulation is performed 10 times using different random number generator seeds, and the average results of multiple simulation runs are reported.

5.2 FCFS with periodic priority sort

The agent record table is sorted with period \( T_{PW} \) using the value of agent record priority \( pw_{Ai} \), which is calculated as follows [3]:

Figure 4: LP and NP jobs in a running state.
where: \( run_{U_j} \) is number of running agents of user \( U_j \) (\( run_{U_j} \geq 0 \)), \( rl_{U_j} \) is user relative load, \( nom_{U_j} \) is nominal priority of user \( j \) (\( nom_{U_j} > 0 \)), \( price_{A_i} \) is user offered job execution price (\( price_{A_i} > 0 \)).

\[
rl_{U_j} = \frac{run_{U_j}}{nom_{U_j}} \quad (4)
\]

\[
pw_{A_i} = \begin{cases} 
price_{A_i}(1 - rl_{U_j}/2), & rl_{U_j} < 2 \\
0, & rl_{U_j} \geq 2 
\end{cases} \quad (5)
\]

Figure 5: Priority \( pw_{A_i} \) calculated using (4) and (5).

Figure 6: FCFS matching \( (T_{PW} = 60 \text{ sec}) \): \( TT_A \) and \( R(90\text{th}/5\%) \).

Figure 7: FCFS matching \( (T_{PW} = 120 \text{ sec}) \): \( TT_A \) and \( R(90\text{th}/5\%) \).

Presented results at Figure 5 shows that for FCFS with periodic sort using priority calculation function (5), an acceptable relation of \( TT_A / price \) is obtained only for an unacceptable short queue sorting period of \( T_{PW} = 60\text{s} \). With doubled, but still short queue sorting period of \( T_{PW} = 120\text{s} \), jobs with slightly higher offered \( price=1.1 \) have considerably lower \( TT_A \) than jobs with \( price=1 \) (Fig. 6). This type of a \( TT_A / price \) discontinuity is not acceptable if computing economy should be applied. Relation of \( R / price \) is not acceptable for both of priority update periods.
5.3 Random matching

To confirm the equality of random generated workload for all price subgroups, the results of pure random matching where all NP price subgroups have the same priority ($price=1$) are presented. Figure 4 and Figure 5 show that each of 5 groups has an acceptable fair access to resources and that the proposed workload could be used for the following step of WR simulation and analysis.

![Figure 4: Random matching: $TT_A$ and $R$](image)

**Figure 8:** Random matching: $TT_A$ and $R$(90th/5%).

5.4 Weighted random matching

The overall results for WR matching showed that the applied scheme gives users a weighted fair access to resources regardless of a long job queue. A higher offered price improves $R$(90th/5%) and $TT_A$ values for all types of jobs. The Figure 8 shows that both $TT_A/price$ and $R/price$ ratios do not show discontinuity, and therefore are acceptable for an implementation of the computing economy. Also, it could be noticed from Figure 8 that offering price above some value does not lead to significant performance improvements. That is as a result of a limited job parallelism for the submitted tasks.

![Table III: WR matching – results.](image)

<table>
<thead>
<tr>
<th>Job size</th>
<th>Price</th>
<th>1</th>
<th>1.1</th>
<th>1.5</th>
<th>3</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>$R$[s]</td>
<td>1860</td>
<td>1837</td>
<td>1226</td>
<td>550.1</td>
<td>345.3</td>
</tr>
<tr>
<td></td>
<td>$TT_A$[s]</td>
<td>5726</td>
<td>5408</td>
<td>4346</td>
<td>2855</td>
<td>2489</td>
</tr>
<tr>
<td>M</td>
<td>$R$[s]</td>
<td>1509</td>
<td>1209</td>
<td>797.4</td>
<td>357.5</td>
<td>212.6</td>
</tr>
<tr>
<td></td>
<td>$TT_A$[s]</td>
<td>3132</td>
<td>2795</td>
<td>2254</td>
<td>1484</td>
<td>1269</td>
</tr>
<tr>
<td>S</td>
<td>$R$[s]</td>
<td>1251</td>
<td>1079</td>
<td>668.8</td>
<td>249.2</td>
<td>140.1</td>
</tr>
<tr>
<td></td>
<td>$TT_A$[s]</td>
<td>1733</td>
<td>1576</td>
<td>1225</td>
<td>791.1</td>
<td>659.1</td>
</tr>
</tbody>
</table>
Figure 9 shows distribution of turnaround times for M size price subgroups. The distributions for S and L size price subgroups have similar shapes. Jobs with higher offer price are more promptly processed (Figure 10).

6. CONCLUSIONS

In this paper we have addressed the problem of Grid intracommunity workload management with the job-pull operational mode, with the goal to simulate and evaluate efficiency of WR matching. The simulation results showed that for a large computing system with 9000 nodes and workloads that consist of uniform and independent jobs, the applied scheme gives each user weighted fair access to computing resources. This also qualifies WR matching to be
drivable by computational economy. Future work will include simulation of more complex workload patterns and implementation of more refined computational economy than presented here.

REFERENCES


SIMULATION RESULTS ON BUFFER ALLOCATION IN A CONTINUOUS FLOW TRANSFER LINE WITH THREE UNRELIABLE MACHINES

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Abstract:
Engineers designing a continuous flow production line consisting of machines and buffers in series, have to determine the optimal sizes of the intermediate buffers. When the machines operating on the product are unreliable, this dimensioning decision becomes even more difficult. This paper aims to provide some insight into the optimal sizes of intermediate buffers in a continuous flow transfer line with three machines and two buffers.

To this end, an extensive series of simulation experiments are performed, and noted the performance (measured as the availability, i.e., the fraction of time that the system as a whole is producing output) under a large variety of different input conditions. The simulation model for this purpose is based on Petri-nets and has been extensively validated prior to this research.

Using these simulation results, we try to find rules to determine where to allocate which amount of buffer space in order to obtain a sufficiently high availability of the system. Different scenarios are simulated: all machines have equal reliability, one machine has significantly higher reliability and one machine has significantly lower reliability. For each scenario, a large number of settings is tested. A careful study of the availability of the system as a function of the sizes of the two buffers reveals some interesting results. We find that the optimal buffer sizes depend strongly on the (relative) reliability of the different machines and that—in general—the performance of the entire system can be considerably increased by correctly choosing the sizes of the two buffers. When all machines are equally reliable, both buffers should be equally large. When the first or the last machine is less reliable, the first respectively the second buffer should be used to dampen the impact of this unreliable machine. Another finding is that if the middle machine is considerably less reliable than the other two, the buffers have far less effect on the performance of the overall system.

The results reported in this paper can be used by practitioners in the field of design of continuous flow transfer line systems to gain insight into the optimal dimensioning of buffers in production systems. Future research in this area will consider simulation models of larger linear systems or more complex networks of machines and buffers. Also, the effects of relaxing one or more of the assumptions made in the simulation model (e.g., on the distribution of up- and down-times of the machines) should be investigated.

Key Words: Production Systems, Simulation, Buffer Allocation, Unreliable Machines

1. INTRODUCTION

Flow-line production systems are mostly associated with products which flow naturally. For example: in a petroleum refining process, the product and the raw material have a propensity to flow. Production systems that output discrete items—such as cars, domestic appliances, etc.—do not possess this natural characteristic unless the items are sufficiently small to be treated as a continuous flow. Wild [19] states that mass production using the flow principle is
one of the most important achievements in manufacturing technology. But even today transfer lines remain the most effective solution for large volume, continuous production of limited variants. In the automotive industry they still are efficient for the production of cylinder heads, cylinder blocks, crank cases and crank shafts.

The problem of designing and improving flow line production systems has received a great deal of attention in the literature. These production systems consist of a number of stages (arranged in series) at which consecutive operations are performed. The machines or equipment are either perfectly reliable or subject to failure. Failure at any stage results in the failure of the entire production system and consequently the overall production rate is affected. The understanding of the machine failures is important in improving the reliability of a transfer line production system.

Algorithms have been developed to estimate performance characteristics of flow lines like throughput, average buffer contents, and blocking and starvation probabilities. A first modelling approach is the open queuing network approach, where each server has its own random processing time. While most approximation methods are quite accurate, they are often computationally complex, due to the number of states increasing with the buffer capacities. In another approach, the goods flow is continuous and the machines have production rates instead of service times. This approach is justified when cycle times are small compared to downtimes and uptimes [5].

In order to improve the availability of the system, two approaches exist. One option is the utilisation of stand-by machines, the other option is to allocate buffer storage between the production stages. Stand-by machines are put into operation in case one of the machines fails. Kubat and Sumita [9] present a dynamic programming model directed at designing a transfer line with standby machines and intermediate buffers of infinite capacity. It allocates the places for the stand-by machines and the buffers in order to maximize the line output rate. The use of redundant machines in an operation mode called ‘splitting’ is considered by Elsayed and Hwang [7]. Each stage in the transfer line consists of two machines with the same operative performance, in regular operation, working at half production rates. When either of the machines fails, the remaining machine doubles its production rate instantaneously. The other option to install buffer storage between a pair of machines aims to avoid the failure of one machine to result in an immediate failure of the entire flow line. The decision how to allocate buffers to a production line is of great practical importance to many industrial systems like oil refining, canning, beverage production and many others.

The behaviour of a system with multiple machines and buffers is very complex. Industrial managers are interested in performance measures of such a system. Availability, i.e. the percentage of time that the line is producing output, is frequently used as an important performance measure. However, closed-form results exist only in very simple cases. In more complex cases either approximation models or simulation models are used.

In the literature on multi-stage lines with finite intermediate buffers, De Koster [6] distinguishes four classes of models. A first class deals with systems in which the service times are random variables and the products are discrete. The machines are not susceptible to failure. A second class assumes deterministic processing times, but machines are unreliable and fail from time to time. Products are discrete. A third class deals with continuous flow models. Machine speeds are deterministic but machines may fail. This is the class of models this paper deals with. Some examples of these models can be found in articles by various authors [2, 3, 8, 10–13, 18, 20]. A fourth class deals with models with discrete products, failures of machines and random processing times.

Furthermore a distinction needs to be made into two types of machines failures: time-dependent and operation-dependent failures. In the former type, the failure only depends on the elapsed time, which means the machine can fail even if it is not working on products. The latter type of failure depends on the time a machine spends working on a product. In real-life manufacturing systems, both types of failures exist. According to Buzacott and Hanifin [2], operation-dependent failures are more common and represent more than 70 percent.

Obtaining analytical results for a system with many machines is considered to be an impossible task. Therefore, approximation or simulation models have to be used to
determine various performance measures. Repeated aggregation over production machines is a useful technique if the output of the aggregated production machine is close to the pattern of two buffered production machines. Aggregation over production machines and an intermediate buffer has been used already by Buzacott [1], who applied it to a fixed-cycle three stage line. Aggregation techniques require the evaluation of the output parameters for two-stage lines. This has been realized by assuming exponentially distributed uptimes and downtimes or by showing how more general two-stage lines can be approximated by this type of exponential lines [4].

The two-machine one-buffer system continuous flow line has been studied in an analytical way by Malathronas et al. [10]. Van Oudheusden and Janssens [17] formulate an approximative aggregation model, in which exponential uptimes and downtimes are assumed, which is useful for a line with three machines. This model is extended by Sörensen and Janssens [14] to include more machines and more buffers.

In Sörensen and Janssens [16], a simulation model based on Petri nets is developed. The advantages of using the Petri net formalism over other simulation models is that it offers some tools to study the properties of the system. Moreover, the computational requirements are not larger than those of other discrete-event simulation models. The Petri net simulation model has a place for each state of each machine and each buffer. The Petri net transitions describe the events that might occur during the simulation and their effect on the state of the system. By adding a time aspect to the Petri net model, it becomes a simulation model that can be used to determine performance measures of an (n-machine n-1-buffer) continuous flow line with unreliable machines. The model initiated in [16] is used to generate the results presented in this paper.

2. CONTINUOUS FLOW TRANSFER LINES WITH UNRELIABLE MACHINES

2.1 Assumptions

![Diagram of a 3-machine 2-buffer continuous flow transfer line.](image)

Figure 1: A 3-machine 2-buffer continuous flow transfer line.

The system studied in this paper consists of a machine with three machines and two intermediate buffers in series. This system is depicted in Figure 1. The following assumptions are made to model the system:

1. Production is continuous. No individual parts can be identified.
2. The system is balanced. All machines operate at the same speed. Production speed is—without loss of generality—assumed to be equal to 1. This means that every machine outputs 1 unit of product per time unit.
3. The first machine cannot be starved. The last machine cannot be blocked.
4. Failure is operation-dependent. A machine can only break down when it is up, not when it is starved or blocked.
5. Failure times and repair times are exponentially distributed and statistically independent. The memory-less property of the exponential distribution allows for a simpler simulation model.

When two or more machines go down, they can be repaired simultaneously. In this paper, we report on extensive simulations of a model of the above system.
2.2 Petri net model

The Petri net model, used to simulate the performance of a continuous flow transfer line system with three unreliable machines and two intermediate buffers, consists of 16 places and 39 transitions. A marking with tokens in some places represents a state of the system.

For easy reference, the transitions are given by their input and output places. A selection of transitions is presented in Table I to obtain a full list of transitions, we refer to the simulation model generation described in Sörensen and Janssens [15] and can be obtained from the authors. Some additional information needs to be kept in variables called token attributes. For each machine, a token attribute is created that contains the amount of time left until the next failure (when the machine is down) or the next repair (when it is up). For each buffer, a token attribute is created that contains the amount of content in the buffer.

From these values, it is obvious to decide which transition fires next. Firing a transition automatically updates the state of the system.

Table I: Selection of transitions of the Petri net model with 3 machines and 2 buffers.

<table>
<thead>
<tr>
<th>Transition No.</th>
<th>Event</th>
<th>Input places</th>
<th>Output places</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1$</td>
<td>$M_1$ down</td>
<td>1 4</td>
<td>2 5</td>
</tr>
<tr>
<td>$T_2$</td>
<td>$M_1$ down</td>
<td>1 5</td>
<td>2 5</td>
</tr>
<tr>
<td>$T_3$</td>
<td>$M_1$ down</td>
<td>1 6 7 11</td>
<td>2 6 9 12</td>
</tr>
<tr>
<td>$T_4$</td>
<td>$M_1$ down</td>
<td>1 6 7 12</td>
<td>2 6 9 12</td>
</tr>
<tr>
<td>$T_5$</td>
<td>$M_1$ down</td>
<td>1 6 7 13 14</td>
<td>2 6 9 13 16</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$T_{38}$</td>
<td>$B_2$ full</td>
<td>5 7 12 15</td>
<td>5 10 11 15</td>
</tr>
<tr>
<td>$T_{39}$</td>
<td>$B_2$ full</td>
<td>1 4 7 12 15</td>
<td>3 4 10 11 15</td>
</tr>
</tbody>
</table>

The simulation logic is as follows:
0. Initialise the simulation.
1. Identify all enabled transitions in the Petri net.
2. Calculate the next-event time for each enabled transition (using the token attributes).
3. Choose the transition with the earliest event time. Move the simulation clock to this time. Calculate the progress of time.
4. Recalculate the token attributes.
5. Fire the transition with the earliest event time. Go to step 1.

2.3 Definitions

The performance of a production system is generally measured by its availability, defined as the ratio of uptime by total time. Some papers use other performance measures. For example, De Koster [6] uses the concept throughput, defined as

$$ q(t) = \lim_{\tau \to t} \frac{\int_{\tau}^{t} q(\tau) d\tau}{t} $$

where $q(t)$ is the actual production at time $t$.

Buzacott and Hanifin [2] use efficiency, defined as

$$ \lim_{\tau \to t} \frac{q(t)}{Q(t)} $$
where \( Q(t) \) is what the production would have been at time \( t \) if the system was perfectly reliable.

In this paper, only availability is used as a performance measure. The availability \( A \) of a system with \( n \) machines and \( n-1 \) buffers is defined as the percentage of time the system is producing output. For a single machine, the following definitions are used:

- The failure rate \( \lambda_i \) of a machine \( i \) is the expected number of failures registered per time unit. The mean time to failure of this machine is \( \text{MTTF}_i = \frac{1}{\lambda_i} \).

- The repair rate \( \mu_i \) of a machine \( i \) is the expected number of repairs performed per time unit. The mean time to repair of this machine is \( \text{MTTR}_i = \frac{1}{\mu_i} \).

- The availability \( A_i \) of a machine \( i \) is given by \( \lambda_i + \mu_i \). \( A_i = \frac{\mu_i}{\lambda_i + \mu_i} \).

2.4 Reading the numbers

The numbers used in these experiments are fictitious. However, when interpreted correctly, we believe they can offer a hint of the size of the buffers to be installed. All buffer sizes should be read relative to the production speed, which is assumed to be 1 unit of product per time unit for each machine. Thus, a buffer with size \( m \) should be interpreted as “a buffer that can be filled by a machine in \( m \) time units”.

In all experiments, we find that the failure and repair rates do not have a significant effect on the availability of the system, as long as the availability of the individual machines is the same. For example, a system composed of machines with \( \mu = 4 \) and \( \lambda = 1 \) behaves in terms of availability very similar to the one with \( \mu = 0.04 \) and \( \lambda = 0.01 \).

3. SETUP OF THE EXPERIMENTS

The following scenarios are tested:

- All machines have equal availability (experiment 1).
- One machine has a considerably higher availability than the other two (experiment 2).
- One machine has a considerably lower availability than the other two (experiment 3).

To obtain a reliable estimate, each value of ‘availability’ in these experiments is computed as the average of 100 individual observations. Simulation runs are long enough for any transition effects to have disappeared (approximately 20,000 time units). For each experiment, 5 different total buffer sizes (0.1, 0.5, 1, 5, 10 and 100) are distributed among the buffers in 20 equal steps. To obtain an estimate of the minimal performance of the system, the availability of the system is calculated when both buffer sizes are set to 0.

3.1 Experiment 1: All machines have equal availability

In this case, the failure and repair rates of the machines are equal \( (\lambda_1 = \lambda_2 = \lambda_3 = \lambda \) and \( \mu_1 = \mu_2 = \mu_3 = \mu \).

In five experiment sets, each machine is assumed to be available respectively 50%, 80%, 90%, 95% and 99% of the time. Assuming exponentially distributed repair times with average duration of 1 time unit, this results in average failure rates of 1, \( \frac{1}{4} \), 1/9, 1/19 and 1/99 time.
Table II: Experiment 1 (all machines have equal availability): maximum availability of the system for different total buffer sizes.

<table>
<thead>
<tr>
<th>$A_i$</th>
<th>0</th>
<th>0.1</th>
<th>0.5</th>
<th>1</th>
<th>5</th>
<th>10</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>25.00%</td>
<td>26.05%</td>
<td>34.29%</td>
<td>34.28%</td>
<td>41.19%</td>
<td>44.67%</td>
<td>49.43%</td>
</tr>
<tr>
<td>80%</td>
<td>57.10%</td>
<td>57.91%</td>
<td>65.34%</td>
<td>65.33%</td>
<td>71.30%</td>
<td>74.57%</td>
<td>79.53%</td>
</tr>
<tr>
<td>90%</td>
<td>75.01%</td>
<td>75.52%</td>
<td>80.52%</td>
<td>80.51%</td>
<td>84.57%</td>
<td>86.46%</td>
<td>89.57%</td>
</tr>
<tr>
<td>95%</td>
<td>86.36%</td>
<td>86.65%</td>
<td>89.60%</td>
<td>89.60%</td>
<td>91.99%</td>
<td>93.01%</td>
<td>94.76%</td>
</tr>
<tr>
<td>99%</td>
<td>97.06%</td>
<td>97.13%</td>
<td>97.79%</td>
<td>97.79%</td>
<td>98.35%</td>
<td>98.56%</td>
<td>98.95%</td>
</tr>
</tbody>
</table>

Figure 2: Availability of a system with total buffer size of 10 and $A_i = 90\%$.

Table II shows the maximum availability for each tested configuration. Figure 2 shows some example results from this simulation experiment. Some general conclusions can be drawn from the results presented above.

1. The more buffer space is installed, the higher the availability will be.

2. The impact of the buffers is larger when the availability of individual machines is low. For example, when individual machines are up 50\% of the time, the availability of the system can be increased by almost 100\%. This number drops fast with rising $A_i$. Stated another way, this fact also means that the impact of not installing intermediate buffers is much more important when individual availability is low. The availability of a system without buffers with $A_i = 50\%$ ($i=1,2,3$) is equal to 25\%, whereas the minimum availability of a system with $A_i = 99\%$, is equal to 97\%.

3. When the buffers become very large, the theoretical availability almost can be reached. This maximum availability is equal to the availability of a single machine.

4. The impact of very small buffers on availability is very small. Consequently, the distribution of buffer space has a larger impact on availability when the total buffer size increases. For small buffer sizes, the distribution is relatively unimportant.

5. Ideally, the buffer space should be equally distributed among both buffers.
6. However, the availability of the system is quite robust with regard to the distribution of buffer space. Although the highest availability is reached when the buffer space is equally distributed among the two buffers, deviations from this ideal distribution do not have a large impact on availability, especially when the total buffer space is very large. In this case, there is “more than enough” buffer space to allow for a high availability, even when the distribution of buffer space is not ideal.

The robustness of availability with regard to the ideal buffer space distribution is important. A manager wishing to minimise the total operating cost may wish to employ a smaller inventory level of high-cost products, as they may represent an important working capital investment. This robustness is highest when the total available buffer space is either very small or very large and arises for different reasons in both cases.

3.2 Experiment 2: One machine has the higher availability

In this experiment, we assume that two out of three machines are up 80% of the time. For these machines, we assume exponentially distributed repair times with average 1 time unit and exponentially distributed failure times with average 4 time units. In three different experiment sets, the better machine is placed first, second and third.

In three different experiments, one of the machines is up 90%, 95% and 99% of the time. If we assume exponentially distributed repair times with average of 1 time unit, failure rates are 1/9, 1/19 and 1/99 respectively. Depending on which of the three machines is the best, the results are quite different. The maximum attainable availability for each tested configuration is shown in Table III.

Table III: Experiment 2 (one machine has higher availability): maximum availability of the system for different total buffer sizes.

<table>
<thead>
<tr>
<th>$A_1$</th>
<th>$A_2$</th>
<th>$A_3$</th>
<th>0</th>
<th>0.1</th>
<th>0.5</th>
<th>1</th>
<th>5</th>
<th>10</th>
<th>100</th>
</tr>
</thead>
<tbody>
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<td>90%</td>
<td>80%</td>
<td>80%</td>
<td>62.08%</td>
<td>62.85%</td>
<td>67.43%</td>
<td>70.09%</td>
<td>73.95%</td>
<td>76.61%</td>
<td>79.73%</td>
</tr>
<tr>
<td>95%</td>
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<td>64.43%</td>
<td>65.08%</td>
<td>67.93%</td>
<td>71.84%</td>
<td>74.91%</td>
<td>77.10%</td>
<td>79.73%</td>
</tr>
<tr>
<td>99%</td>
<td>80%</td>
<td>80%</td>
<td>66.27%</td>
<td>66.90%</td>
<td>68.99%</td>
<td>73.21%</td>
<td>75.94%</td>
<td>77.56%</td>
<td>79.77%</td>
</tr>
<tr>
<td>80%</td>
<td>90%</td>
<td>80%</td>
<td>62.03%</td>
<td>62.86%</td>
<td>70.22%</td>
<td>70.18%</td>
<td>74.70%</td>
<td>77.19%</td>
<td>79.81%</td>
</tr>
<tr>
<td>80%</td>
<td>95%</td>
<td>80%</td>
<td>64.40%</td>
<td>65.15%</td>
<td>72.20%</td>
<td>72.24%</td>
<td>75.71%</td>
<td>77.70%</td>
<td>79.81%</td>
</tr>
<tr>
<td>80%</td>
<td>99%</td>
<td>80%</td>
<td>66.23%</td>
<td>66.96%</td>
<td>73.56%</td>
<td>73.60%</td>
<td>76.22%</td>
<td>77.87%</td>
<td>79.81%</td>
</tr>
<tr>
<td>80%</td>
<td>80%</td>
<td>90%</td>
<td>62.08%</td>
<td>62.80%</td>
<td>70.05%</td>
<td>67.42%</td>
<td>73.97%</td>
<td>76.60%</td>
<td>79.76%</td>
</tr>
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<td>64.34%</td>
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<td>69.47%</td>
<td>75.71%</td>
<td>77.70%</td>
<td>79.81%</td>
</tr>
</tbody>
</table>
3.2.1 The first machine has higher availability.

![Graph](image.png)

Figure 3: Availability of a system with total buffer size of 100 and $A_1 = 95\%$ (caused by higher MTTF), $A_2 = A_3 = 80\%$.

Figure 3 shows some detailed example results. The most important conclusion from this experiment is that availability increases most if more space is allocated to the second buffer than to the first. This can be understood by reasoning that—since the first machine has a higher availability than the second—the second machine almost never is starved, regardless of the size of buffer 1. Moreover, the third machine has the same availability as the second, implying that it is starved more often. Therefore, increasing the second buffer increases the availability of the system. This effect is noticeable in every experiment, even in experiments with very small buffer spaces. It is stronger in cases where the first machine has a very high availability and the total buffer space is either very small or very large. In these cases, the optimal availability is obtained when almost all buffer space is allocated to the first buffer. When the total buffer space is neither very small nor very large, the ideal distribution occurs when the greater part of the buffer space is allocated to the first buffer and a smaller part to the second.

Some other conclusions from these experiments are:

1. Total availability rises with the amount of buffer space installed.

2. Total availability rises only little with the quality of the better machine.

3. The impact of installing buffer space is higher when the availability of the better machine is low. This results from the fact that the room for improvement is lower when this machine has higher availability.

4. The improvement caused by the better machine—compared to the situation where all machines are equal—is higher when the installed buffers are small. Installing buffers thus reduces the effect of having a better machine.

5. With very large buffers, the highest possible availability can almost be reached. Of course, the highest possible availability in this case is the availability of the worst machine, in this case of machines 2 and 3.

6. The impact of very small buffers on availability is very small.
3.2.2 The third machine has higher availability.

Some example results are shown in Figure 4. When the third machine is better than the other two, the availability is highest when the first buffer is larger than the second. Because the third machine has a significantly higher availability, the second machine almost never is blocked, regardless of the size of the second buffer. The availability of the entire system can therefore be increased most by installing a large first buffer and a smaller second buffer. The conclusions 1 to 6 in the previous section are equally valid in this case.

3.2.3 The second machine has higher availability.

When the second machine is significantly better than the other two, the relation between the availability of the entire system and buffer allocation is significantly less strong than in the case where all machines have equal availability. An example of this behaviour can be seen in Figure 5. For example, the maximum increase of availability in Figure 5 is less than 3%. An explanation can be found in the fact that, since machine 2 is significantly better, buffer 1 is close to empty most of the time and buffer 2 is close to full most of the time, regardless of the respective sizes of these buffers. This implies that machine 1 almost never is blocked and that machine 3 almost never is starved. When this happens, the buffers become useless and lose their role as buffers. For some cases, this happens regardless of the allocation of the buffer space. In this situation, it is best to install as little buffer space as possible. It occurs when the total buffer volume is either very low or very high. As a general conclusion, it can be stated that when the second machine is better than the other two machines, availability rises slowly with a rise in total buffer volume.
3.3 Experiment 3: One machine has lower availability

In this experiment, we assume that two of the three machines have 95% availability. For these machines, we assume exponentially distributed repair times with average 1 time unit and exponentially distributed failure times with average 19 time units. This corresponds to an average availability of 95%.

In three different experiment sets, the worst machine is placed in first, second or third place. We assume availability of 50%, 80% and 90% for this machine. If we assume exponentially distributed repair times with average of 1 time unit, failure rates are 1, 1/4 and 1/9 respectively. Results from this experiment are shown in Table IV.

Depending on which of the three machines is the best, the results are quite different. However—as can be seen in Table IV—the maximum availability is roughly the same in all scenarios.

Table IV: Experiment 3 (one machine has lower availability): maximum availability of the system for different total buffer sizes

<table>
<thead>
<tr>
<th>$A_1$</th>
<th>$A_2$</th>
<th>$A_3$</th>
<th>0</th>
<th>0.1</th>
<th>0.5</th>
<th>1</th>
<th>5</th>
<th>10</th>
<th>100</th>
</tr>
</thead>
<tbody>
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<td>47.49%</td>
<td>47.84%</td>
<td>48.72%</td>
<td>49.64%</td>
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<td>50.07%</td>
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<tr>
<td>80%</td>
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<td>82.23%</td>
<td>82.65%</td>
<td>83.84%</td>
<td>87.60%</td>
<td>88.60%</td>
<td>89.62%</td>
<td>90.04%</td>
</tr>
</tbody>
</table>

Some general conclusions can be drawn from these data:

1. If the availability of the worst machine is low, the availability of the system is close to the maximum attainable availability. Of course, the maximum availability is equal to the availability of the worst machine. This can be called the *weakest-link effect*. The worst machine keeps the performance of the system low, regardless of the quality of the better machines.
2. The fact whether the worst machine is first, second or third does not have a large impact on the maximum availability of the system. Total availability is roughly the same in all three cases.

3. When the availability of the worst machine is rather large, the room for improvement grows. In these cases, the weakest-link effect is much less prominent and the provision of buffer space becomes more important.

3.3.1 The first machine has lower availability

In this case, there is a slight preference for a larger first buffer. However, the relationship between buffer allocation and availability is weak.

3.3.2 The third machine has lower availability

When the third machine is worse than the other two machines, slightly more buffer space should be allocated to the second buffer. Again, the relationship between buffer allocation and availability is weak.

3.3.3 The second machine has lower availability

The ideal buffer allocation in this case is when both buffers are of equal size. This is illustrated in Figure 6. Even with relatively small buffers, the availability is close to optimal at all times, especially when the availability of the second machine is low. Therefore, deviations from the ideal buffer allocation only cause small decreases in availability. This can be understood by reasoning that most of the time buffer 1 is full and buffer 2 is empty, resulting from the fact that machine 1 is better than machine 2 and machine 2 is worse than machine 3. The buffers lose much of their function in this case.

![Figure 6: Availability of a system with total buffer size of 5 and $A_2 = 50\%, A_1 = A_3 = 95\%$.](image)

4. CONCLUSIONS

In this paper, extensive simulation results on the allocation of buffer space in a continuous flow transfer line with unreliable machines are discussed. Simulation results are collected from a Petri net simulation model of a line with three machines and two buffers. It is shown...
how these results can be used to find some generally applicable rules of thumb for the allocation of buffer space in a continuous flow-line.

REFERENCES

A SYSTEM MODEL FOR GREEN MANUFACTURING

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Abstract:
Manufacturing systems evolution is function in multiple external and internal factors. With today’s global awareness of environmental risks as well as the pressing needs to compete through efficiency, manufacturing systems are evolving into a new paradigm. This paper presents a system model for the new green manufacturing paradigm. The model captures various planning activities to migrate from a less green into a greener and more eco-efficient manufacturing. The various planning stages are accompanied by the required control metrics as well as various green tools in an open mixed architecture. The system model is demonstrated by an industrial case study. The proposed model is a comprehensive qualitative approach to design and/or improve green manufacturing systems as well as a roadmap for future quantitative research to better evaluate this new paradigm.

Key Words: Green Manufacturing, Planning and Control

1. INTRODUCTION

The term green manufacturing was coined to reflect the new manufacturing paradigm that employs various green strategies and techniques to become more eco-efficient. These strategies include creating products/systems that consumes less material and energy, substituting input materials (e.g. non-toxic for toxic, renewable for non-renewable), reducing unwanted outputs and converting outputs to inputs (recycling).

As in any of the previous manufacturing paradigms, this new green manufacturing paradigm is an outcome of market and technological drivers. Higher global awareness of environmental risks as a result of the new green movement is shaping new customer requirements in many places. In addition, the evolving green technology together with more eco-friendly product designs is helping in realizing the green manufacturing objectives in real practice.

Although interest in green manufacturing is increasing more and more within the research and industrial communities, a clear description of what is meant by this term is becoming more essential. Much confusion arises from failing to describe the meaning, impact and implementation of green manufacturing at various level of manufacturing. In other words more work is required to differentiate between green manufacturing on the operational level, process level and system level. Furthermore, the relation between sustainability and green manufacturing needs to be better explained to avoid mixing the two terms and at the same time drawing a clear relation between them.

This paper presents a system model for the new green manufacturing paradigm. The model captures various planning and control activities required to migrate from a less green into a greener and more eco-efficient manufacturing. The model is an attempt to better explain green manufacturing and at the same draw a qualitative roadmap for green manufacturing realization.
2. GREEN AS A COMPETING MANUFACTURING STRATEGY

Companies all over the globe are under pressure from stakeholders to be eco-efficient (Klebnikoff 1996) [7]. Justification to invest and implement green manufacturing techniques (or the ROI as sometimes called) stems from three main aspects. These aspects are briefly discussed as follows:

Green manufacturing and Efficiency:

Time is money, energy is money and consumables are money. Making the same product using fewer resources and/or energy is a good strategy to make money. In other words, being efficient through preventing waste is both eco as well as money efficiency. In manufacturing there are a lot of wastes that can be eliminated in the process as well as the product. Green manufacturing strategy to reduce wastes is outlined in Figure 1.

Green manufacturing and Market Share:

With new customer demands and higher awareness together with tougher global competitiveness pressure, manufacturing enterprises need to review their manufacturing strategies. Green manufacturing should be viewed as an opportunity to expand the local and global market share in this dynamic environment. A deeper understanding of green manufacturing strategies and techniques will enable manufacturers to realize that unlike other competing manufacturing strategies, being green positively impact all other manufacturing competitive edges (as shown in Figure 2).

Green manufacturing and government support and regulations:

Pressure from governments to evolve into green manufacturing is increasing. Thinking globally, EU, Asia, US, South America, the whole world’s governments and even the UN are developing more regulations, penalties, tax benefits or obligations to become greener. Thus green manufacturing techniques are becoming more and more a mandate rather than being an option when manufacturers think globally.

Based on the previous aspects, the transformation of current manufacturers into becoming greener can be economically justified. Integrating technological enablers with this economical understanding makes prospective green manufacturing a reality.
Figure 2: Green manufacturing and competitive manufacturing strategies.

3. GREEN MANUFACTURING AND SUSTAINABILITY

The definition of sustainability which is generally adopted is: “meeting the needs of the present generation without compromising the ability of future generations to meet their own needs” (World Commission on the Environment and Development, 1987) [11]. With this definition all eco-friendly approaches, methodologies and research to preserve environmental conditions and resources through wastes reduction, prevention or recycling can be categorized under sustainability. Sustainability is a concept and a paradigm that has its different implementation and interpretation at different fields. For example, it is defined in the business field as “adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining and enhancing the human and natural resources that will be needed in the future” (Deloitte & Touche 1992) [3].

Green manufacturing deals with maintaining sustainability’s environmental, economical and social objectives in the manufacturing domain. The author proposes the relation between sustainability as a concept and green manufacturing as a methodology in the following definition of green manufacturing: Green manufacturing is a sustainable approach to the design and engineering activities involved in product development and/or system operation to minimize environmental impact.

4. REVIEW ON GREEN MANUFACTURING

The available work on green manufacturing in its modern new context is considered to be few. The review can be divided into two groups, first, the work that dealt with the overall concept of green manufacturing and second, the work that provided various analytical tools and models to realize green manufacturing at different levels.

Examples of the first group is the work of Mohnty and Deshmukh (1998) [10] highlighting the importance of green productivity as a competitive edge. They defined green productivity as all activities attempting to decrease wastes. They showed various case studies with different waste elimination practices to highlight the potential green productivity can have on the overall manufacturing performance. Naderi (1996) [11] showed that green manufacturing is highly tied to waste management through the elimination of causal factors. Jovane et al. (2003) [4] presented sustainable and green manufacturing as future paradigm with business model based on designing for environment using new nano/bio/material technologies. They highlighted that the new paradigm will respond to the customer need of more eco friendly products. Wang and Lin (2007) [13] proposed a broad triple bottom line framework to track and categorize sustainability information at the corporate level through a sustainability index.
Ahmed M. Deif: A System Model for Green Manufacturing

system. The framework incorporated environmental and social costs and values into economic activities to support the decisions of the management. Their methodology was suggested to help decision makers to make green manufacturing plans. Burke and Goughran (2007) [2] also presented another framework for sustainability to realize green manufacturing. The framework was based on their studies of SME manufacturers who achieved ISO 14001 certification.

Examples for the second group include the work of Melnyk et al (2001) [9] who proposed Green MRP tool. This tool is essentially a conventional Material Requirements Planning system that has been modified to include environmental considerations when converting the Master Production Schedule into the various component schedules. Through this inclusion, Green MRP solves the problem of minimizing environmental impact when managing industrial waste, by flagging potential component planning and environmentally related problems. Fiskel (1996) [5] gathered different analytical tools that have emerged from product/process design research for green manufacturing. Examples of these tools include Life Cycle Analysis (LCA), Design for the Environment (DfE), screening methods and risk analysis. Hui et al. (2002) [6] proposed a model to assess environmental hazards in manufacturing. In their model, the network analytic method was employed to analyze the potential of each impact category created by different kinds of waste in manufacturing processes. Additionally, fuzzy set theory was used to determine a numeric fuzzy weighting factor of each impact category contributing to the overall potential environmental impact on ecosystem. The model was limited to ecological health hazards. For realizing green manufacturing on the machine level, Krishnan et al. (2004) [8] proposed environmental value systems analysis tool to evaluate the environmental performance of semiconductor processing. The tool develops environmental assessments through a “bottom-up” analysis approach, assembling equipment environmental models to describe a system. Cleanability and burr reduction which are another green manufacturing aspects also on the machine level were studied in various machine tool researches to act as another optimisation objectives in their attempts to improve machine tool performance. Example of this type of work was presented by Avila et al (2005) [1] in the aerospace industry.

The above review is generally attempting to describe various aspects of green manufacturing as a concept and how to partially implement various technologies to improve green level. A required step to build on the overall available literature is having a holistic overall approach to realize green manufacturing. In other words, the literature of green manufacturing is missing a clear roadmap for manufacturing enterprises that can asses the current level of their greenness and offer a structured transformation plan towards becoming greener. This paper proposes a system model approach to fill this required gap.

5. SYSTEM MODEL FOR GREEN MANUFACTURING

The general purpose of developing systems models is to discover high-level frameworks for understanding certain kinds of systems, their subsystems, and their interactions with related systems. Thus, the purpose of the proposed green manufacturing system model is to better understand green manufacturing in terms of:

- Capturing the various activities required to assess the current green level of the manufacturing system.
- Outlining the green transformation plan and the various tools and control metrics required in this transformation.
- Describing how to sustain the achieved improvements and build on it to maintain more eco-efficient systems.
Figure 3: System model for green manufacturing.

Figure 3 shows system model architecture for the design and control of the green manufacturing systems. The architecture is composed of two modules; the first module describes the design and planning processes of the green manufacturing systems and the second module describes the control process that controls the design and planning process at each level. The control module is based on performance measurements that reflect the strategic objectives and constraints indicated by the high-level decision makers at each level. The architecture as shown is open for that its information flow is accessible through any layer and it is mixed as it is composed of both hierarchal and partitioned levels. The architecture is made of four layers which will be discussed and explained in the following sections.

5.1 What is your colour?

Any improvement process starts from assessing the current situation. The objective of this layer of the green manufacturing design and planning process is to identify how green the system is. The assessment process should be multidimensional where the level of greenness is measured across different manufacturing levels from operational level up to the system level. The challenge at this stage is to have a quantified assessment process. You cannot improve what you cannot measure. The quantitative assessment results (or assessment metric) will rank the manufacturing system with respect to green manufacturing benchmark targets or practices of the specified industry (in other words, what is their current color with respect to green). Furthermore, the assessment values will be used over the green transformation process as performance measure as well as improvement targets.

Green manufacturing metric (G2M) is a suggested metric under development by the author to fill the current need to have a comprehensive quantitative assessment measure. The metric will manipulate data gathered about the waste level (in terms of materials and energy), eco level (in terms of impact), and existing green culture in the manufacturing system to act as inputs to a weighted mathematical formulation of the desired assessment. Various techniques can be used to gather input data including structured surveys, scorecards, impact...
analysis and the new developed technique called green stream mapping (or GSM). Artificial intelligence techniques (such as fuzzy and agent systems) are investigated to be used to quantify both qualitative and quantitative measured data into the new metric. The metric values will reflect the green score with respect to each level in the manufacturing system. The assessment layer inputs, mechanisms, controls and output are explained using International Definition (IDEF0) model shown in Figure 4.

5.2 Prepare your brush

In this layer, green improvement/implementation plan is generated in light of the previous assessment score. The planning phase is bounded by maintaining the required production level to meet market demand. This is particularly important to ensure manufacturers that green improvements or implementation will not negatively affect their productivity as traditionally assumed. The planning development should be carried out at the operational (machine) level, the process level and the system level with preset order dictated by the assessment score. The developed plan will include qualitative and quantitative action items with regard to material and energy type and consumption, process modifications and adjustments and finally technology implementation and improvement.

The generation of the plan at this stage is primarily and optimisation process due to the nature of the objectives and various system constraints. The objective function will hold competing objectives like minimizing both energy consumption as well as material while maintaining a minimal cost. The constraints in this optimal plan will be achieving productivity that meets the demand, desired quality level as well as acceptable time. Various techniques should be explored to generate this plan like analytical hierarchical process (AHP), constraint satisfaction problem (CSP) techniques, theory of constraint, and various meta-heuristics techniques. The plan will be realized through translating optimal energy and material levels to layout modification requirements, optimal process parameters, optimal control parameters as previously mentioned. An IDEF0 model for green improvement/implementation planning layer is shown in Figure 5.
5.3 Paint it green

The next step after the development of the optimal plan is to gradually implement it. Each aspect of the plan (material, energy, process and technology) is decomposed and implemented either separately or concurrently with other aspects. A structured methodology should be developed for that implementation that maintains a balance between the current system configuration and practices and those of the optimal plan to ensure gradual transformation without affecting productivity.

Upon the implementation of the green manufacturing plan at each level, a reassessment process using the developed green manufacturing metric should be carried out. The reassessment process will measure the green improvement degree at various manufacturing levels achieved through the plan. Based on the assessment the plan will be judged as successful or not. An IDEF0 model for green manufacturing plan implementation layer is shown in Figure 6.

![Figure 6: IDEF0 model for green manufacturing plan implementation layer.](image)

5.4 Keep it green

The real success of any improvement in manufacturing is measured by the degree of its sustainability. Green manufacturing realization should have sustainability as an inherent component in any green planning activity. Green manufacturing policies and guidelines are one expected output at this stage. In addition, the continuous measurement of the greenness level at the various manufacturing levels together with green kaizen groups should be part of the normal planning and control activities in green faculties.

![Figure 7: IDEF0 model for sustaining green manufacturing implementation layer.](image)

The problem at this stage of green transformation process is a typical dynamic control problem. The feedback of the continuous greenness measurement should trigger other green
improvement plans and the process continuously goes on and on. An IDEF0 model for sustaining green manufacturing implementation layer is shown in Figure 7.

**6 INDUSTRIAL CASE STUDY**

In this section, the proposed system model is illustrated by an industrial case study. The case study involves different activities to improve the greenness level of a wood products manufacturer at its paint dept. The primary focus was the paint line of a specific product (shutters) which involved spray priming, sanding and spray printing. The process at that line can be summarized in the following steps: they apply a light primer coat, dry, sand, apply a heavier primer coat, dry, sand, apply a coat of paint (lacquer), sand where needed and finally, a second and final coat of lacquer (shown in Figure 8).

![Diagram of Shutters paint line process](image)

**Figure 8: Shutters paint line process.**

Figure 9 explains how the wood products manufacturing achieved a successful implementation of green manufacturing activities using the proposed system model. Table I displays the annual cost, time, material and environmental savings for the implemented green manufacturing activities. Both Figure 9 and Table I demonstrate the feasibility and efficiency of the structure green manufacturing methodology offered by the proposed system model architecture.

Table I: Annual cost, time, material and environmental savings for implemented green manufacturing activities.

<table>
<thead>
<tr>
<th>Reductions</th>
<th>Source of Savings</th>
<th>Annual Cost Savings</th>
<th>Annual Time, Material &amp; Environmental Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour/Increased capacity</td>
<td>New filter system</td>
<td>$3,800</td>
<td>Over 160 hours</td>
</tr>
<tr>
<td>Material</td>
<td>Avoided paint purchase (raw material) due to new paint container design</td>
<td>$1,440</td>
<td>48 gallons/year</td>
</tr>
<tr>
<td></td>
<td>Improved transfer efficiency</td>
<td>$34,530</td>
<td>102 gallons primer 980 gallons of lacquer</td>
</tr>
<tr>
<td>Emissions</td>
<td>Improved transfer efficiency</td>
<td>Not quantified</td>
<td>968 pounds VOCs 82 pounds hazardous air pollutants (HAPS)</td>
</tr>
<tr>
<td>Disposal</td>
<td>Filters (longer life)</td>
<td>Not quantified</td>
<td>Not quantified</td>
</tr>
<tr>
<td></td>
<td>PVC scrap to recycler</td>
<td>$670</td>
<td>6 tons scrap PVC</td>
</tr>
<tr>
<td>Water</td>
<td>New flush/purge water methods</td>
<td>$3,000</td>
<td>1200 gallons/year</td>
</tr>
<tr>
<td>Energy</td>
<td>Reduced use of evaporators due to improved water use</td>
<td>$3,000</td>
<td>120,000 kwh electricity</td>
</tr>
<tr>
<td><strong>Total cost savings</strong></td>
<td><strong>$46,740</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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7 SUMMARY AND FUTURE WORK

This paper presented a system model approach to realize green manufacturing. An open mixed architecture for the design, planning and control of green manufacturing activities was developed. The architecture describes the green manufacturing transformation process.
starting from determining the current green level of the manufacturing system (what is your colour) to developing an optimal green plan (prepare your brush) to implementing the developed plan (paint it green) to finally sustaining the green improvements (keep it green).

The system approach recognized that the green transformation is carried at different levels, mainly operational (machine), process and finally system level. The developed architecture also showed how each layer is controlled by different performance measurements that reflect the strategic objectives of the green manufacturing system. In addition, each the mechanisms, tools and expected output of each layer were highlighted using international definition IDEF0 models.

The proposed system model for green manufacturing was demonstrated through an industrial case study. The successful improvement of the greenness level of the paint dept. in the considered case highlighted the efficiency of the planning and control activities included in the presented system approach.

The architecture is considered a comprehensive explanation of the green manufacturing systems and opens the door for researchers to visualize the different areas that need to be developed in such systems. For example, various quantitative metrics together with various analytical techniques were suggested and recommended. This architecture is considered a novel architecture to tie different aspects of the design, planning and control of green manufacturing systems.

Future work is required to take the proposed qualitative system model into a quantitative level. Metrics like G2M, optimal green manufacturing plans algorithms, and structured green implementation methodology are examples of these quantitative requirements. Finally, industrial case studies are required to demonstrate the application of the proposed system model.

REFERENCES

FACILITY LOCATION MODEL FOR REVERSE LOGISTICS

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Abstract:
This paper presents a study that characterizes, formulates, and solves the reverse logistic network design. A Mixed Linear Program model is formulated that systematically minimizes reverse logistics operating costs for the strategic problem facility location of collection sites, cannibalization and recycling. The facility location is a central issue of the logistics networks. In this paper we are interested in optimizing of the sites facility location for product end of life reverse logistics network. This model allows determining to open or to close the sites previously in the reverse logistics network. The decisions mentioned above are taken to minimize the cost of products recovery at the end of life. We wish to solve the problem of site facility location site in a reverse logistics network for various times of time considered in strategic planning. The inclusion of such an element means to solve a multi-time step problem: decisions taken at a given time are related to those taken in previous times and take account of future needs. To solve the mathematical program, we have used the evaluation and separation process implemented in CPLEX commercial solver. A numerical analysis on a test case illustrates the model formulation and the proposed model.

Key Words: Logistics, Reverse Logistics, Facility Location, End of Life Product, Location Problem, Mixed Linear Program

1. INTRODUCTION

Logistics is a vast field. Classical definitions of the word “LOGISTICS” appear in several works: “Greek mathematicians called logistics the art of calculating”. In our context, logistics is “the art of transferring and transforming matter and information together and Just-in-Time with the permanent concern about the safety of people and goods, and preserving the environment”. In large industrial companies “we can see that upstream logistics (supplies), often linked to the manufacturing logistics, differs from downstream logistics, within which distribution and after-sales often come under different services and circuits. Furthermore, downstream from consumption, developed “return” logistics complete the circuit. Logistic integration does not result in its organisational unification… Integrated logistics is a notion rather than an operational reality.” The notion of integrated logistics for an industrial company brings together three aspects:

- Integration of industrial management technologies,
- Integration of safety and the environment in the production system,
- Finally, integrating the partners in view of searching for outside skills.

The company-network concept requires a scattered productive organisation in which searching for physical flows – and information flows – is quite complex. This complexity stems from the nature of the flows dealt with and also from the different environments called upon in order for this organisation to be successful. The production modes differs according to the company network’s mesh, the distances that separate them, etc.

Reverse logistics can be defined as the reverse process of logistics [1]. Traditionally, reverse logistics has been viewed primarily as the process of recycling products. Today, definitions vary depending on what company or segment of industry is attempting to de0ne it. Retailers see reverse logistics as a way to get product that has been returned by
a consumer back to the vendor [2]. Manufacturers tend to view reverse logistics as the process of receiving defective products or reusable containers back from the user. The Council of Logistics Management (CLM) defines reverse logistics as “The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal” [3]. Reverse logistics generally involves events necessary to retrieve, transport and dispose of goods. These goods are moved backward from the consumer and the process includes the information flows associated with tracking and credit processes.

Reverse logistics focuses on the backward flow of materials from customer to supplier (or alternate disposition) with the goals of maximizing value from the returned item and/or assuring its proper disposal [4]. This may include product returns, source reduction, recycling, materials substitution, reuse of materials, waste disposal, refurbishing, repair, and remanufacturing. Reverse logistics processes—and reverse logistics research—has traditionally emphasized green logistics, i.e., the use of environmentally conscious logistics strategies [5]. While environmental aspects of reverse logistics are critically important, many firms are also recognizing the economic impact of reverse logistics [6]. Recent research suggests that companies can recapture value through an efficient and effective returns process [7].

Three types of decisions are involved in the decision problem related to the design of the reverse logistics network: the first concerns the sites facility location. The second concerns the flow of matter and information between these entities. Finally, the third is investment in labor and equipment in each of these facilities. In literature, these three categories of decisions refer to the problems of facility location, allocation and capacity [8]. For the facility location decision, it usually means selecting the most appropriate among previously identified potential sites in order to optimize one or more objective functions. In our research work, we focus specifically on modeling the problem of sites facility location in a reverse logistics network for product end of life.

[9] address the problem of localization in two approaches. The first is to add reverse logistics to a network of existing logistics while the second is to make a new logistics network. It is in second position that we're interested. Specifically, we seek to determine:

- The sites to open or close from a set of previously defined sites.
- The flow of material from these sites.

The decisions mentioned above are taken to minimize the cost of products recovery at the end of life. We wish to solve the problem of site facility location site in a reverse logistics network for various times of time considered in strategic planning. The inclusion of such an element means to solve a multi-time step problem: decisions taken at a given time are related to those taken in previous times and take account of future needs.

In the following sections, a literature review and related research work are illustrated in Section 2; this is followed by Section 3 which provides a discussion of our research problem, the conceptual model and the formulation model using Mixed Linear Program; In section 4 we present an illustrative example; Section 5 concludes the paper and provides suggestions for future research.

2. LITERATURE SURVEY

The facility location problem for the reverse logistics network has been the subject of several studies. One of the first models to localize the center of recovery is that proposed by [10]. They describe a management system for solid waste in Lambardy region (Italy) including collection, transportation, recycling and disposal. They use a multi-objective model. [11] Propose a model to minimize the total treatment cost of reusable containers using a special case of a localization classic model. It is a mixed linear program model. [12] Present a model for the spent recycling in the Netherlands in order to minimize the total cost of recovery network.
Describe a Mixed Linear Program model for secondary products (uses) recovery. They assume that the quantity of secondary products is proportional to the amount of primary (new). In addition, they assume that returns are not necessarily returned to the outlet that delivered the product of departure, they can be returned at any open site.

Present a linear programming model for the design of a network of recovery of the end of life products. This model is composed of several collection sites, a treatment site and several clients whose returns are known. The problem is to determine the number of collection sites and to initiate treatment in order to minimize the total cost of distribution around. They assume that returns can be routed directly to the treatment center without the intermediary of a collection center, the capacity is limited.

Propose a multi-objective linear model for the recovery of obsolete computers in New Delhi. It adds the transport of hazardous materials risks between collection sites of treatment and risks in the different sites that constitute the network.

Propose a linear programming model to give decision support to determine the collection sites, recycling and landfill open for the recovery of waste materials while limiting the capacity of sites. It aims to minimize the operational costs of the logistics network for product recovery at the end of life.

Propose a linear programming model to locate sites in a reverse logistics network. These intermediate centers where used products are disassembled, cleaned and sorted to be transported to the remanufacturing sites (remanufacturing centers) in which the parts from the used products are used to manufacture new products.

When we review the literature on the facility location of sites in a reverse logistics network, we find that the models developed so far are based on a classical model of locating warehouses which are added one or two elements for reverse logistics as capacity, number of facilities open, non-negativity of decision variables, on the one hand. On the other hand, we note that the majority of models are single-time which cannot measure the impact of long-term decisions. Note also that most models proposed in the literature were developed for a reverse logistics network structure (no authorization flow between sites). Some models are easily adaptable from one network to another. Finally, they do not reflect environmental costs (emission of toxic gases) generated by hazardous materials.

3. PROBLEM STATEMENT

Most location models developed so far are models of single-product or single time. Indeed, some models are not adaptable for a network to another. Moreover, they do not take account of dynamism of reverse logistics program. To overcome these drawbacks, we propose a generic model multi-product and multi-time site locations for the reverse logistics of products at the end of life in order to minimize logistics costs. The proposed model can be used to solve the facility location problem of sites for varied structure networks.

The proposed model refers to the structure of the reverse logistics network shown in Figure 1. In this network, the company gets the products at the end of life returned by its customers through its collection sites. After their yards, they are transported to treatment sites. Some will be disposed of in landfill (e.g. hazardous materials). Further, they will be recycled (metal and plastic). Once processed, finished products from the recycling are used for the manufacture of new products which will then be offered to consumers and consumed. To specify the study scope and facilitate model formulation, four assumptions and simplifications in the proposed model formulations are postulated as follows:

- The location of potential sites for the collection and treatment is known at time t.
- The costs of opening the site and transportation costs are known in advance.
- The capacity of each site is limited to the time.
- The cost of investment and divestiture of a portion of capacity at a site from one time to another are fixed.
The various costs considered in the different nodes are: opening site cost and cost of unit transportation of products at the end of life...

Several products at the end of life to be recovered by the company.

No storage in the collection site

![Reverse logistics network Structure for product end of life](image)

The proposed model aims to determine the sites to open or to close each time and the flow of goods between the different sites that make up the reverse logistics network (site collection, site recycling and landfill).

**Indices**
- $p$: End of life Product index, $p = \{1, \ldots, P\}$
- $i$: Customer, $i = \{1, \ldots, I\}$
- $j$: Potentiel collection site, $j = \{1, \ldots, J\}$
- $t$: Time time, $t = \{1, \ldots, T\}$, ($T$: planning horizon)
- $k$: Potentiel Recycling site, $k = \{1, \ldots, K\}$.
- $k'$: Potentiel landfill site, $k' = \{1, \ldots, K'\}$.

**Parameters**
- $F_{jt}$: Fixed cost of collection site $j$ opening in time $t$
- $F_{kt}$: Fixed cost of recycling site $k$ opening in time $t$
- $F_{k't}$: Fixed cost of landfill site $k'$ opening in time $t$
- $C_{piji}$: Cost of end of life product $p$ transporting from customer $i$ to the collect site $j$ at time $t$
- $C_{pjkt}$: Cost of end of life product $p$ transporting from collection site $j$ to the recycling site $k$ at time $t$
- $C_{pjk't}$: Cost of end of life product $p$ transporting from collection site $j$ to the landfill site $k'$ at time $t$
- $B_{jt}$: Collection site $j$ capacity at time $t$
- $D_{kt}$: Recycling site $k$ capacity at time $t$
- $E_{k't}$: Landfill site $k'$ capacity at time $t$
- $Y_{\text{max}}$: Maximum number of collection sites to open
Decision variables

$Y_{jt}$ Binary variable equal to 1 if site $j$ is open at time $t$

$Z_{kt}$ Binary variable equal to 1 if site $k$ is open at time $t$

$W_{k't}$ Binary variable equal to 1 if site $k'$ is open at time $t$

$X_{pjit}$ End of life products quantity stored at customer $i$ and transported to the collection site $j$ in time $t$.

$X_{pjkt}$ End of life products quantity to recycled and transported from the collection site $j$ to recycling site $k$ at time $t$.

$X_{pjk't}$ End of life products quantity to eliminate and transported from the collection site $j$ to landfill site $k'$ at time $t$.

Using above indices and parameters; the mathematical formulation standard for this problem can be stated as follows.

Min $A = \sum_j \sum_t F_{jt} Y_{jt} + \sum_k \sum_t F_{kt} Z_{kt} + \sum_{p_j} \sum_j C_{pjit} X_{pjkt} + \sum_{p_j} \sum_k \sum_t C_{pjkt} X_{pjk't} + \sum_{p_j} \sum_k \sum_{t'} C_{pjk't'} X_{pjk't'}$

Subject to

$\sum_j X_{pjit} \geq G_t \quad \forall p, \forall i, \forall t$ (1)

$\sum_j X_{pjit} = \sum_k X_{pjkt} + \sum_{k'} X_{pjk't} \quad \forall p, \forall i, \forall t$ (2)

$\sum_{p_j} \sum_i \sum_j X_{pjit} \leq B_{jt} Y_{jt} \quad \forall k, \forall t$ (3)

$\sum_{p_j} \sum_i \sum_k X_{pjkt} \leq D_{kt} Z_{kt} \quad \forall j, \forall t$ (4)

$\sum_{p_j} \sum_{k} \sum_{k'} X_{pjk't} \leq E_{k't} W_{k't} \quad \forall j, \forall t$ (5)

$\sum_{p_j} \sum_i \sum_j X_{pjit} \leq M Y_{jt} \quad \forall k, \forall t$ (6)

$\sum_{p_j} \sum_i \sum_j X_{pjit} \leq M Y_{jt} \quad \forall k, \forall t$ (7)
The main objective of this mathematical model is the determination of the collection and treatment sites (site of recycling and landfill) location in each time and the flow between these sites. This model aims to minimize the costs of end of life products recovery. The mathematical model specifies the variety of end-of-life product and multiple times.

The constraint (2) describes that all the end of life products are collected by the company. Float balance between the different sites is assured by constraint (3). The respect of the available capacity is provided by the constraint (4, 5, 6). Constraints (7), (8) and (9) ensure that if a site is closed, the flow of incoming and outgoing products are zero, M is a size constant. The respect of opening site constraint is provided by the constraints (10, 11, 12). Constraint set (13) check for binary variables and the last constraint s (14) check for the non-negativity of decision variables.

4. RESULTS AND DISCUSSIONS

We apply our model on a dataset taken from the literature on the reverse logistics of electronic products at end of life in India, Indeed, electronic products end of life will reach 217440 tones in 2010 in India [15]. Using a numerical example, we will illustrate how the model works in the proposed framework and gain some insights into the proposed model. A small set of data is prepared reflecting the real business situation. Indeed, the company recovers the end of life product of its customers to be sorted and disassembled in the collection sites. Hazardous products will be disposed of in landfills. Materials will be transported to recycling sites. The reverse logistics network for the application is composed of: 3 customer, 9 collection site, 7 recycling site, 2 landfill site, 4 times’ time and 6 end of life products. We obtained the results using a Windows XP, Pentium 4, 2.4 GHz and 160 GB of memory (Figure 2). Figure 3 shows potential site of collection, recycling and landfill to open in every time.
The results of the case of application considered are shown in the Table I.

Table I: Numerical results of the application.

<table>
<thead>
<tr>
<th>Constraint number</th>
<th>Total variable</th>
<th>Binary variable number</th>
<th>Execution time (s)</th>
<th>Optimal cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>885</td>
<td>2665</td>
<td>72</td>
<td>33.5</td>
<td>693150</td>
</tr>
</tbody>
</table>

The optimal cost is found 693,150 including three collection sites, three recycling sites and two landfills are open. CPLEX found the optimal solution after 33.5 minutes second. In the time 4, three collection sites will be open because the quantity of returns less than in the first time. Thus, the proposed model allows taking into account the dynamism of a reverse logistics system. Moreover, we note that when we increase the number of times considered in the strategic planning, logistics costs are declining. This can be explained by increasing
the quantity of products at the end of life recovered. However, we note that the costs increase significantly in establishing a strategic planning on 9 times (Figure 4).

5. CONCLUSIONS

Compared to early literature on addressing end life recovery and facility location, the model found in this study has two distinctive features. First, by coordinating the critical activities of reverse logistics management, the proposed method addresses the classical network of end life product treatment problem with a generic model. Second, in this work, we established a multi-product and multi-time location of sites for the reverse logistics of the end of life products. The proposed model can be applied to varied structure reverse logistics network. It can determine the state of sites, their openness, closure, available capacity and material flow between the various entities of the logistics network. All decisions shall be taken to minimize logistics costs. However, we considered that the returns quantity is deterministic and that investment in the capacity of a site is fixed. In literature the problem of facility localization is an NP-hard problem. To solve the mathematical program, we use the evaluation and separation process located in a commercial solver Cplex. The modeling problem of the facility location in reverse logistics network sites is an open area of research.

REFERENCES

APPLYING DMAIC PROCEDURE TO IMPROVE PERFORMANCE OF LGP PRINTING PROCESS COMPANIES

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Abstract:
The light-guide-plate (LGP) luminance plays an important role in producing liquid crystal displays (LCD) panels of quality images. Poor luminance usually results in producing LCD panels with color defects. This research aims at improving the performance of LGP printing process by following the define-measure-analyze-improve-control (DMAIC) procedure.

To improve the performance of LGP process, the DMAIC procedure will be implemented as follows. Process mapping and control charts will be established in the define-phase. The process capability analysis is conducted in the measure-phase. The Taguchi’s experimental design and analysis will be performed in the analyze- and improve-phases. Finally, the grey model GM (1,1) will be employed in the control-phase.

Utilizing the Taguchi’s L_{27} (3^{13}) array, six key process factors were investigated concurrently; including scraper angle, scraper pressure, scraper speed, ink viscosity, ink paller bearing, and gap between board and LGP. It is found that the scraper’s angle, pressure and speed, and ink viscosity significantly contributed to the luminance variability. The anticipated improvement in luminance is found 512 cd/m^2. The estimated process capability, C_{pl}, is greatly enhanced from 0.69 to 2.44.

Statistical quality control tools, the Taguchi method, and GM (1,1) grey model are employed in the DMAIC procedure to improve the performance of LGP process. Product/process engineers can adopt this procedure in a similar manner to enhance the performance of any manufacturing process in a wide range of business applications.

Key Words: Taguchi Method, DMAIC, Statistical Quality Control, GM (1,1) Grey Model

1. INTRODUCTION

Because of its smaller space requirement, high-quality display and acceptable cost, the thin film transistor liquid crystal display (TFT-LCD) has become the most important visual display terminal screen today [1–4]. TFT-LCD is used widely in the industry of electronic information displays, including television, mobile phones, digital cameras and other consumer related communications hardware. In such products, image colour-quality has been recognized as one of the top considerations in the display manufacturing industry and has become a benchmark that influences consumers’ purchasing decision.

The light-guide-plate (LGP) luminance plays an important role in producing LCD panels of quality images and it is used in assessing front-of-screen quality. Poor luminance results in producing LCD panel with colour defects, which increase quality costs. Hence, improving the performance of LPG process is the main focus of this research.
Six sigma [5] is a project-driven management approach to improve products and processes by continually reducing defects. A widely-accepted six sigma approach is the DMAIC procedure, which was adopted to improve the performance for numerous manufacturing processes [6, 7]. Further, the introduction of robust design proposed by Taguchi [8] in quality engineering resulted in significant quality and productivity improvements in product and manufacturing process design. Taguchi method [9] combines engineering ideas with statistical techniques in novel ways and offers tremendous potential for quality improvement with minimal cost in a wide range of industrial applications [7, 10].

This research, therefore, aims at improving luminance of LCD for LGP printing process using DMAIC procedure including the Taguchi method. The remaining of this paper is outlined in the following sequence. Section two performs the define-phase. Section three carries out the measure-phase. Section four performs the analyze- and improve-phases. Section five establishes the control-phase. Section six summarizes conclusions.

2. DEFINE-PHASE

2.1 Mapping Backlight Module Processes

A conventional LCD backlight module is composed of light sources, LGP, and optical sheets; such as, reflection, diffusion, and prism sheets. In this module, the light rays from the source are incident on one of the LGP sides and are guided inside it based on the principle of total internal reflection. At least one of LGP surfaces is coated with an ink layer. The ink layer contains a plurality of diffusing granules for diffusing lights to produce uniform luminance.

The flow chart of backlight module is rooted in Figure 1. Initially, the LGP cutting and cleaning take place. Dot patterns are then printed on its surface. The LGP is fitted with lamp set then assembled with module frame and optical film. Screen inspection, testing, and film protection activities follow. Packing of the back-light module is finally performed. Among the back-light module processes, the LGP printing process is a critical process in producing quality modules, which is performed on LGP printing machine shown in Figure 2.

2.2 Assessing the process performance

The $\bar{x}$ and $R$ control charts are widely applied for on-line monitoring of the mean and variability of the manufacturing processes [11]. They are a proven technique for improving productivity, defect prevention, preventing unnecessary process adjustment, and providing information about process capability. Let $UCL$, $CL$, and $LCL$ denote the upper control limit, the central line, and lower control limit, respectively. The $\bar{x}$ and $R$ control charts are concluded in control if all points fall within control limits and no indication of significant patterns or runs between the control limits.
Five LGP plates are randomly chosen then inspected every two hours for 15 working hours. On each plate, the luminance is measured with BM7 at five points (L_1, L_2, L_4, L_7, L_9) as depicted in Figure 3. The luminance average and range are calculated for each LGP. The corresponding $\bar{x}$ and $R$ control charts are finally constructed then shown in Figure 4. The LCL, CL, and UCL for the $\bar{x}$ chart are calculated and found equal to 4480.3, 4625.2, and 4770.2 cd/m$^2$, respectively. For the $R$ chart, the LCL, CL, and UCL are estimated 0.0, 251.3, and 531.4, respectively. In Figure 4, no point is detected outside the control limits nor are any significant patterns or runs observed within the limits of both control charts. Consequently, the $\bar{x}$ and $R$ control charts are concluded in control.
3. MEASURE PHASE

Process capability analysis [12] is a vital part of an overall quality-improvement program by which the capability of a manufacturing process can be measured and assessed. In practice, the process standard deviation, $\sigma$, is unknown and frequently estimated as:

$$\hat{\sigma} = \frac{\overline{R}}{d_2}$$

where $d_2$ is a constant related to sample size. The one-sided actual process capability, $C_{pk}$, attempts to take the process mean into account [13]. The estimator of $C_{pk}$, $\hat{C}_{pk}$, is calculated as:

$$\hat{C}_{pk} = \min(C_{pu} = \frac{USL - \hat{\mu}}{\hat{\sigma}}, C_{pl} = \frac{\hat{\mu} - LSL}{\hat{\sigma}})$$

where $USL$ and $LSL$ are the upper and lower specification limits, respectively. The $\hat{\mu}$ is the estimate of $\mu$ and is equal to the $CL$, $\overline{X}$, of the $\overline{X}$ chart. A value of 1.67 is considered the standard minimum boundary for $\hat{C}_{pk}$. In this research, the $LSL$ of luminance is 4450 cd/m$^2$ (candelas per square meter). Using the $\overline{X}$ ($= 4625.2$ cd/m$^2$) and $\overline{R}$ ($= 251.3$ cd/m$^2$), and the $d_2$ for a sample size of five is equal to 2.326, the $\hat{\sigma}$ and $\hat{C}_{pk}$ values are calculated by Equations (1) and (2) and found equal to 108.04 cd/m$^2$ ($= 251.3/2.326$) and 0.695 ($= (4625.2 - 4450)/(3 \times 108.04)$), respectively. Evidently, the LGP printing process is concluded incapable for providing acceptable luminance.
Figure 4: The $\bar{x}$ and $R$ charts at initial and optimal factor settings.
4. ANALYZE- AND IMPROVE- PHASES

4.1 Investigating critical QCH and process factors

The LGP luminance is considered the key measurable and continuous QCH of main interest. The cause-and-effect diagram for non-uniformity of LGP luminance is shown in Figure 5.

![Cause-and-effect diagram for non-uniformity](image)

Figure 5: The cause-and-effect diagram for luminance non-uniformity.

Six control factors may affect the capability of the LGP printing process including: (A) scraper angle, (B) scraper pressure, (C) scraper speed, (D) ink viscosity, (E) ink paller bearing, and (F) gap between board and LGP. Based on process knowledge, all factors A to F are assigned at three levels. The corresponding level values are displayed in Table I. The combination of factor settings of the LGP printing process at initial stage is A_1B_2C_2D_2E_1F_2.

**Table I: The physical values of factor levels.**

<table>
<thead>
<tr>
<th>Control factor</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Scraper angle (degree)</td>
<td>65°</td>
<td>75°</td>
<td>85°</td>
</tr>
<tr>
<td>B. Scraper pressure (bar)</td>
<td>P_0-1</td>
<td>P_0</td>
<td>P_0+1</td>
</tr>
<tr>
<td>C. Scraper speed (mm/sec)</td>
<td>S_0-20</td>
<td>S_0</td>
<td>S_0+20</td>
</tr>
<tr>
<td>D. Ink viscosity (cP)</td>
<td>C_0-5</td>
<td>C_0</td>
<td>C_0+5</td>
</tr>
<tr>
<td>E. Ink paller bearing (bar)</td>
<td>T_0</td>
<td>T_0+5</td>
<td>T_0+10</td>
</tr>
<tr>
<td>F. Gap (mm)</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

* The poise is the most commonly encountered unit of viscosity, often as the centipoise (cP).

4.2 Improving performance using Taguchi method

Taguchi method mainly focuses on finding the optimal setting of control factors involved in a system to make its performance insensitive to noise. An orthogonal array (OA) is used to provide an experimental design. Signal-to-noise (S/N) ratio is then employed to measure performance and decide optimal factor levels. In this research, the L_{27} (3^{13}) array shown in Table II is selected to investigate the six process factors concurrently.
Table II: Experimental results for $L_{27} \left(3^{13}\right)$ array.

<table>
<thead>
<tr>
<th>Exp. ($j$)</th>
<th>Factor-columns assignment</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Average luminance</th>
<th>S/N ratio ($\eta_l$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
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<td>1</td>
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<td>1</td>
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<td>1</td>
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<td>4</td>
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<tr>
<td>5</td>
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<td>2</td>
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<td>6</td>
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<td>7</td>
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<td>3</td>
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<td>8</td>
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<td>9</td>
<td>1</td>
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<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
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<tr>
<td>10</td>
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<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
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</tr>
<tr>
<td>11</td>
<td>1</td>
<td>2</td>
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<td>3</td>
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<tr>
<td>12</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>13</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<td>14</td>
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<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
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<td>15</td>
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<td>1</td>
<td>3</td>
<td>3</td>
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<td>3</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
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<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>17</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
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<td>2</td>
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<td>20</td>
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<td>22</td>
<td>3</td>
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<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
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<tr>
<td>23</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>24</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>25</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>26</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>27</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

In practice, larger luminance provides better performance. The corresponding S/N ratio, $\eta_l$, is expressed as:

$$\eta_l = -10 \log_{10}\left(\frac{1}{n} \sum_{i=1}^{n} 1/y_i^2\right), \; i=1,\ldots, I; j=1,\ldots, J$$  

where $y_i$ is the luminance average of each test $i$ for experiment $j$. Three repetitions ($n = 3$) are conducted at the same factor levels of each experiment. The last column of Table 2 summarizes the estimated S/N ratios values for all experiments. For illustration, the S/N ratio, $\eta_l$, of 73.11 dB for the first experiment is calculated as using Eq. (3) as follows

$$\eta_l = -10 \log_{10}(1/4498^2 + 1/4536^2 + 1/4536^2)/3 = 73.11 \text{ dB}$$

The $\eta_l$ values for the other 26 experiments are estimated similarly.

 Typically, a larger S/N ratio indicates better performance. The S/N ratios averages are calculated at each factor level then depicted in Figure 6. Consequently, the combination of optimal factor levels is $A_3B_3C_3D_2E_3F_2$. Table 3 tabulates the luminance averages for all factor levels. The anticipated improvement in luminance, due to setting process factors at $A_3B_3C_3D_2E_3F_2$, is calculated for each factor as the luminance at optimal factor level minus that at initial factor level. The last column of Table 3 lists the obtained results. The total
anticipated improvement is calculated and found equal to 512 cd/m², where factors A, B, and C contributed the largest effect on the anticipated improvement of luminance.

Figure 6: Plot of S/N ratios averages (optimal level is identified by circle).

Table III: Luminance averages for all factor levels.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Luminance (cd/m²)</th>
<th>Anticipated Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level 1</td>
<td>Level 2</td>
</tr>
<tr>
<td>A. Scraper angle (degree)</td>
<td>4839</td>
<td>4937</td>
</tr>
<tr>
<td>B. Scraper pressure (bar)</td>
<td>4768</td>
<td>4874</td>
</tr>
<tr>
<td>C. Scraper speed (mm/sec)</td>
<td>4843</td>
<td>4917</td>
</tr>
<tr>
<td>D. Ink viscosity (cP)</td>
<td>4853</td>
<td>4962</td>
</tr>
<tr>
<td>E. Ink pallier bearing (bar)</td>
<td>4880</td>
<td>4912</td>
</tr>
<tr>
<td>F. Gap (mm)</td>
<td>4914</td>
<td>4922</td>
</tr>
<tr>
<td>Total Improvement (cd/m²)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.3 Determining significant factor effects

To determine the process factor with significant effects on LGP luminance, analysis of variance (ANOVA) is conducted. The results are displayed in Table IV.
Table IV: ANOVA for luminance.

<table>
<thead>
<tr>
<th>Factor</th>
<th>SS_i</th>
<th>df_i</th>
<th>( \rho_i ) (%)</th>
<th>MS_i</th>
<th>F ratio</th>
<th>SS'_i</th>
<th>( \rho'_i ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>84905.73</td>
<td>2</td>
<td>9.99 %</td>
<td>42452.87</td>
<td>10.35</td>
<td>76705.03</td>
<td>9.02 %</td>
</tr>
<tr>
<td>B</td>
<td>539602.07</td>
<td>2</td>
<td>63.5 %</td>
<td>269801</td>
<td>65.80</td>
<td>531401.4</td>
<td>62.50 %</td>
</tr>
<tr>
<td>C</td>
<td>94882.98</td>
<td>2</td>
<td>11.16 %</td>
<td>47441.49</td>
<td>11.57</td>
<td>86682.28</td>
<td>10.19 %</td>
</tr>
<tr>
<td>D</td>
<td>57047.48</td>
<td>2</td>
<td>6.71 %</td>
<td>28523.74</td>
<td>6.96</td>
<td>48846.78</td>
<td>5.75 %</td>
</tr>
<tr>
<td>E</td>
<td>26707.76</td>
<td>2</td>
<td>3.14 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>602.23</td>
<td>2</td>
<td>0.07 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>46496.35</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Pooled error</td>
<td>(73806.34)</td>
<td>18</td>
<td></td>
<td>(4100.35)</td>
<td>12.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>850244.61</td>
<td>26</td>
<td></td>
<td></td>
<td>100 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Pooled sum of squares (SSs) are identified by an underscore.

In ANOVA, the sum of squares (SS) contributed by each of the control factors A to F. The percentage contribution \( \rho_i \) by factor \( f \) in total sum of squares (SS_T) is then adopted to evaluate its importance on the quality characteristic of interest, which can be expressed as [14]:

\[
\rho_i = \frac{SS_i}{SS_T} \times 100 \%
\]

(4)

The pure percentage contribution by factor \( f \), \( \rho'_i \), is calculated as:

\[
\rho'_i = \frac{SS'_i}{SS_T} \times 100 \%
\]

(5)

where \( SS'_i \) is the pure sum of squares contributed by factor \( f \). Given the degrees of freedom, \( df \), associated with factor \( f \), the \( SS'_i \) is calculated as:

\[
SS'_i = SS_i - df_f \times V_e
\]

(6)

where \( V_e \) is the pooled error mean square obtained as pooled error variance divided by degree of freedom associated with pooled error. In this research, a factor effect is considered negligible if it is associated with a percentage contribution \( \rho \) less than 5 %. Consequently, the effects of factors E (\( \rho_E = 3.14 % \)) and F (\( \rho_F = 0.07 % \)) are considered negligible and hence their sum of squares values are pooled into error. Moreover, the effects of factor A to D are significant as their corresponding F ratios of 10.35, 65.80, 11.57, and 6.96, respectively, are greater than 4. The values of \( \rho_A, \rho_B, \rho_C \) and \( \rho_D \) for factors A to D are found 9.02 %, 62.50 %, 10.19 %, and 5.75, respectively. Obviously, the scraper pressure (factor B) contributes the largest pure sum of squares and hence is considered the most influential factor on luminance. Moreover, factors A, B, C, and D contribute about 87 % of the total variability in LGP luminance.

### 4.4 Confirmation experiments

Conducting confirmation experiments is a crucial final step of a robust design which verifies that the optimal factor levels do indeed the projected improvement. Settings process factors at the combination of optimal levels \( A_3B_3C_2D_2E_3F_2 \), five samples are randomly selected every half hour for 15 working hours. Their corresponding \( \bar{x} \) and \( R \) control charts are constructed then also shown in Figure 4. At improvement stage, the \( LCL, CL, \) and \( UCL \) values for the \( \bar{x} \)
chart are estimated 4857.60, 4949, and 5040.40 cd/m², respectively. Whereas, for the R chart the LCL, CL, and UCL values are calculated 0, 158.4, and 334.86 cd/m², respectively. Obviously, the \( \bar{x} \) and R control limits at improvement stage are tighter than those at initial stage. Moreover, the \( \hat{\sigma} \) value at improvement stage is 68.10 cd/m². The \( \hat{C}_{pk} \) value at improvement stage is enhanced to 2.44, which indicates that the LGP printing process become highly capable.

5. CONTROL–PHASE

The grey system theory, originally presented by Deng [15], focuses on model uncertainty and information insufficiency in analyzing and understanding systems via research on conditional analysis, forecasting and decision making. The grey model GM(1,1) has been successfully applied to various applications [16]. The benefits from the use of grey forecasting models are that: (i) it can be used to situations with the minimum data down to four observations; (ii) it utilizes a first-order differential equation to characterize a system; and (iii) the computation is very simple using computer software. The GM(1,1) grey model is summarized as follows [17]:

**Step 1.** For an initial time sequence

\[
X^{(0)} = \{x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(i), \ldots, x^{(0)}(n)\}
\]

where \( x^{(0)}(i) \) the time series data at time \( i \), \( n \) must be equal to or larger than four.

**Step 2.** Establish a new sequence \( X^{(1)} \) through the accumulated generating operation in order to provide the middle message of building a model and to weaken the variation, that is

\[
X^{(1)} = \{x^{(1)}(1), x^{(1)}(2), \ldots, x^{(1)}(i), \ldots, x^{(1)}(n)\}
\]

where

\[
x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i) \quad k = 1, 2, \ldots, n
\]

**Step 3.** Construct a first-order differential equation of grey model GM(1,1) as follows

\[
\frac{dX^{(1)}(k)}{dt} + aX^{(1)} = b
\]

and its difference equation is

\[
X^{(1)}(k) + aZ^{(1)}(k) = b \quad k = 2, 3, \ldots, n
\]

where \( a \) and \( b \) are the coefficients to be estimated using

\[
[a, b] = \left[ \begin{array}{cc}
-Z^{(1)}(2) & 1 \\
-Z^{(1)}(3) & 1 \\
& \\
& \\
-Z^{(1)}(n) & 1 \\
\end{array} \right]^{-1} \left[ \begin{array}{c}
-Z^{(1)}(2) \\
-Z^{(1)}(3) \\
& \\
& \\
-Z^{(1)}(n) \\
\end{array} \right] + \left[ \begin{array}{c}
-Z^{(1)}(2) \\
-Z^{(1)}(3) \\
& \\
& \\
-Z^{(1)}(n) \\
\end{array} \right] + \left[ \begin{array}{c}
x^{(0)}(2), x^{(0)}(3), \ldots, x^{(0)}(n) \\
\end{array} \right]^T
\]

54
and \( Z^{(i)}(k+1) \) is the \((k+1)^{th}\) background value calculated as

\[
Z^{(i)}(k+1) = \frac{(x^{(i)}(k) + x^{(i)}(k+1))}{2} \quad k=1,2,...,(n-1)
\]

Solving Equation (12) gives

\[
a = \frac{\sum_{k=2}^{n} z^{(i)}(k) \sum_{k=2}^{n} x^{(i)}(k) - (n - 1) \sum_{k=2}^{n} z^{(i)}(k) x^{(i)}(k)}{(n - 1) \sum_{k=2}^{n} z^{(i)}(k)^2 - \left( \sum_{k=2}^{n} z^{(i)}(k) \right)^2}
\]

and

\[
b = \frac{\sum_{k=2}^{n} z^{(i)}(k)^2 \sum_{k=2}^{n} x^{(i)}(k) - \sum_{k=2}^{n} z^{(i)}(k) \sum_{k=2}^{n} z^{(i)}(k) x^{(i)}(k)}{(n - 1) \sum_{k=2}^{n} z^{(i)}(k)^2 - \left( \sum_{k=2}^{n} z^{(i)}(k) \right)^2}
\]

**Step 4.** Obtain the predicted \( \hat{x}^{(i)}(n + p) \) at time \((n+p)\) using

\[
\hat{x}^{(i)}(n + p) = \left(x^{(i)}(1) - \frac{b}{a}\right)(1 - e^{a})e^{-a(n+p-1)}
\]

Utilizing the 10 confirmation experiments in Figure (4) as an initial sequence, the steps of GM (1,1) grey model were performed. The \(a\) and \(b\) values are calculated using Equation (14) and (15) and found equal to 0.00153233 and 4993.25839, respectively. The predicted luminance is calculated using Equation (16) and found as:

\[
\hat{x}^{(i)}(n + p) = 4989.53104e^{-0.00153233(n+p-1)}
\]

where \(p\) is the number of periods to be predicted ahead from the 10th period. Figure 4 also displays the predicted luminance for samples 11–20. The above model was verified by predicting the confirmation values, where the square root of mean square error is found equals 47.69 cd/m$^2$, which is considered negligible. For a three sigma quality-level, the range for predicted luminance is about 150 cd/m$^2$ which is very small. Consequently, the prediction model may provide a good estimate of luminance for future production.

6. **CONCLUSIONS**

This research aims at improving LGP printing process by adopting DMAIC methodology. The process mapping, \( \bar{x} \) and \( R \) control charts, process capability, Taguchi method, and GM(1,1) model are the main tools used in this methodology. Six process factors were investigated concurrently, including: scraper angle, scraper pressure, scraper speed, ink viscosity, ink paller bearing, and gap between board and LGP utilizing the L$_{27}$ (3$^{13}$) array. The S/N ratio was then employed to decide optimal factor levels. By implementing DMAIC, the anticipated improvement in luminance is 411.13 cd/m$^2$. The \( C_{pi} \) was greatly enhanced from 0.69 to 2.44. Moreover, the scraper’s angle, pressure and speed, and ink viscosity were found significantly contributing to the total variations of LGP printing process.
REFERENCES


MANAGERIAL APPLICATIONS OF FRAMING EFFECTS AND MENTAL ACCOUNTING IN NETWORK PARTICIPATION

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Abstract:
Metropolis such as Tehran might be treated as an example of the cities on their ways to be modernized being faced with emerging problems and issues. With respect to the efficiency of the civil sophisticated experts' ideas for resolving the civic difficulties, an intelligent database named "Idea Bank" has been implemented in Tehran municipality since 2009. The aim of this paper is showing some solutions for enhancing the efficiency and effectiveness of the idea bank system based on framing effects (FE).

Based on extensive review of FE, broad ranges of general case of FE are identified. Then, through field studies and using questionnaire tools, the degree of the applicability of each particular FE lows is determined. The research procedure finally led to the identification of applicable FE in enhancing the performance of idea bank network.

The results show the application of sunk cost, bundle/unbundle framing of outcomes and Penny-a-day strategy can effect on generating ideas in the idea bank. Also Pseudo certainty effect could reduce idea bank's awards expenses even the amount of reduction illustrated quantitatively.

This work contributes to a more innovative view at framing effects and its psychological effects on effectiveness of expert's decision making in the idea bank.

The results of this study could be applied similarly in enhancing the productivity of suggestion systems in organizations or even in contributing of experts in social networks.

The paper should be of value to researchers of FE in general, and to implementers of FE theory programs in social networks.

Key Words: Framing Effects, Mental Accounting, Judgment and Decision Making

1. INTRODUCTION

During recent years, with considerable expansion of Tehran, capital of Iran, the municipality, has been always encountered with critical problems in effectiveness and efficiency of civil issues, for instance mismanagement, misconduct of projects and misallocation of resources. To overcome these problems, the municipality needs to codify different kinds of long and short term plans. Those plans must have especial attributes like: applicability, effectiveness, efficiency with consideration of opportunities, threats, weaknesses and strengths. Therefore the Strategic Committee Department of Municipality crucially needs outward ideas from experts of all related civic fields; and a data base for scrolling and maintaining the ideas, based on which a system would be enabled to collect the best ideas and have those mentioned attributes for the municipality senior managers. We called this system "Municipality Idea Bank". Creating an idea bank which is able to collect best ideas can provide
many opportunities. By developing such an idea bank, two results will be achieved for the municipality: first solving its own problems, second, increasing the level of citizen participation. The components of this system are hardware, software with interface applications and human. The productivity of this system would depend on subjective values of participants. Satisfying these subjective values that are naturally countless will be possible in existence of rich recourses which definitely are not available in the municipality. Therefore there should be a method or a tool, consistent with the above mentioned values.

In order to achieve this satisfaction, in the idea bank, framing theory, based on a mental model [1], [2], [3], [4] has been applied. This theory is investigated in many sciences (as well as politics, economics, marketing, treatment etc.) (e.g., [3], [5], [6]). They have well determined the framing phenomenon and its functions in each of the mentioned sciences. They have demonstrated that how framing causes paradoxes in people's judgments and decision making and also how the consequences violate the normative theory. In this regard we can mention to the studies of Thaler in which he investigated the framing effects and usages in people's mental accounting and consumer behaviors [3], [7]. For example consider company A in its advertisements: "60% of our company's products have ability to compete in international market".

The other side of this message is that; 40% of their products are not qualified for international market. Definitely the first message would have stronger positive impact on stakeholders' judgment. This example is one of simple kinds of framing manipulation (In framing literature this kind of framing called "Attribute framing"). Many scholars have demonstrated the usage of framing effects in political and public relationships that are used by elites. Chong describes framing as the essence of public opinions formation [5]. Furthermore, Druckman discusses how public conflicting perspectives can effect (prior) elite framing effects [5].

In this article we intend to investigate this theory in experts' participation area in the idea bank of municipality with a practical approach that so far has not been analyzed in any studies. In addition, although the relationship between the framing and mental accounting is in the mental models extent, has been rarely studied [8]. This relationship will be also investigated in this research. The literature review section covers framing effects. After describing the research method, in the studies part, empirical tests would be applied in order to answer the hypothetical questions. Finally the article discusses the studies' findings and implications.

2. FRAMING EFFECTS AND MENTAL ACCOUNTING

Framing is one of the most famous controversial issues, which deviates from the rational decision theory [3], [9]. Judgment and decision making are very sensitive to the way that decision outcomes are manipulated [8], [10]. Whether this manipulation, aims at challenging the willingness to risk, simply evaluating of an object or persuading a communication (see., [10]). Basically rational decisions follow the normative model of expected-utility theory [12]. According to this model, decision outcomes should not violate the principle of description invariance [12]. Based on this principle the way that a decision scenario is manipulated in different states or situations should not change individual choices. But in framing by differently manipulating of a decision problem, even contradictory choices would be made because it objectively emphasizes part of the problem's information that biases people's decision to a choice that does not follow a rational process, it rather follows subjective values [13].

Daniel Kahneman and Amos Tversky in 1979 proposed a descriptive theory of decision utility, which is called "prospect theory". This theory illustrates the famous type of framing called Risky-choice framing, because it can challenge people's judgment by risky vs. certain options. [1], [2]. It is the most widely used type of framing in researches [10], [14]. In this type, "individuals tend to prefer risk-averse alternative when the outcomes are framed in term of gains (e.g., saving lives, making money), but shift to preferring risk-seeking when the equivalent outcomes are framed in terms of losses (e.g., dying, losing money)"([5], P.63).
Prospect theory contains one of the most robust human biases called “loss aversion” and is defined as the individual tendency to avoid losses in exchange for obtaining equal gains [16]. This bias causes risk seeking behaviour because from psychological point of view losses (e.g., losing 1000$) seem more painful and tormentor than equal gains (e.g., gaining 1000$) [17]. The result of this dissatisfaction in risky framing, biases decision to more risky choices. In the idea bank contributing an idea equates paying cost. Obtaining award/s or satisfying expectations equals to gain. Kessler, Ford and Bailey found that loss of a favourable object produces a negative value in prospect theory [9], similarly losing award/s or the failure of an idea equals loss. This claim is retrieved from mental accounting studies. In this study prior to presenting the framing effect, we have investigated sunk cost effect that might be considered as the basic concepts in mental accounting (e.g., [3], [6]).

2.1 Sunk-cost

It is when a person pays the price of a service or good in advance or has a previous investment in something then opens a mental account for the service [3], [18]. A person can simultaneously open different mental accounts for different services and if the sunk cost be greater the pressure of using the service increases, [6], [18]. The account will close when the person gains the same value by consuming the service [18], [19]. If giving an idea is equal to paying money, therefore an expert who contributes his/her idea, creates a mental account at the time of contribution and will close it with satisfaction when he/she gets his/her award (or gains) from the idea bank. Therefore we would like to argue that sunk cost is not just limited to monetary matters. So in the study 1 we will answer the following hypothesis:

H1: contribution in the idea bank like other monetary decision problems create sunk cost for the experts in the idea bank.

This hypothesis means that although mental accounting generally involves monetary outcomes (e.g., paying $40 to get a ticket of a football match), idea generation is one of the exceptions and would produce the same consequences as in mental accounting.

“Loss aversion would have little impact on decision making if people aggregate multiple decisions together” ([20], p. 193). For example Chema and Soman presented a vacation package program in two different versions and asked subjects’ opinion about the attractiveness of each of them. One version framed just with a bundled price of services (e.g., airfare, hotel, and transferor totally cost $2000) while another framed with unbundled prices of each service in a booklet (i.e., airfare cost $500, hotel cost $1400, and transferor cost $100 totally cost $2000). The first version was more appealing to try for the subjects than the second one [18].

When the information of a decision problem is aggregated it shapes broad framing. This decreases the pressure for consumption. On the other hand segregating the information shapes narrow framing which increases consumption’s pressure [6]. For example if four tickets are being purchased for $160, it is quite clear how much each ticket costs and to forego using that tickets in each time would feel like a $40 loss(narrow framing). However, if a four ticket coupons is purchased or pass for $160(a bundled transaction), it is easier to shift money around (e.g., to think that three of the tickets cost $50 each and the Fourth was only $10). In other words, there is more room for creative mental accounting. The end result is that it is easier to forego using that final ticket [6]. These effects in the idea bank may help in the way that problems are displayed, because we think that aggregating or segregating problems in ideation may have impact on amount of contribution like consumer behavior in monetary matters. Therefore the second hypothesis is:

H2: the broad framing of decision problem in idea bank increase contribution in comparison to narrow framing. And narrowly manipulation of idea bank decision problem increase pressure for gaining the award.

Both of these hypothetical questions are investigated in the second study.
2.2 Pseudo certainty effect

The combination of loss and gain valence in risky-choice framing creates "Pseudo certainty effect". This kind of framing manipulation is mostly considered as an illusion. It occurs when the problem is broken in two parts. In the first part the framing must be fully risky and negative in order to make the decision maker a risk seeker, for the remaining part, the problem should be presented in the following manipulation: certain and positive option vs. risky and positive option. By this framing in the second stage most of decision makers choose the certain option [1], [18]. Tversky and Kahneman([2], p. 455) have concluded that "a decision problem is evaluated conditionally(i) when there is a state in which all acts yield the same outcome, such as failing to reach the second stage of the problem(ii)and the stated probabilities of other outcomes are conditional on the nonoccurrence of this state". We use this phenomenon in the Idea Bank as a method to decrease some expenditure, especially those awards that cost a lot for the municipality.

H3: Pseudo certainty can be applied to reduce the Idea Bank's expenditure.

Experts' expect variety of awards in the Idea Bank. For example from a simple concert ticket up to an outsourced construction project (e.g., an expert whose idea has been accepted in the Idea Bank and is a civil engineer and may have a Construction Company, might ask municipality for outsourcing the project that he/she had previously contributed an idea for it). Experts hope a portfolio of awards before contribution, therefore any method that can decrease amount of award is of great value for the system. We have investigated this hypothesis in the third study.

2.3 A pennies-a-day strategy

One of the most applicable framing manipulation which can be well recruited in advertisements [18], called "A pennies-a-day strategy ". Gourville got a tricky manipulation that traders use in their advertisements, they reframe a business deal from aggregate payment to series of continuous small daily payments [18]. For instance in a donation activity, one group of subjects was asked whether they like to pay 85cents (PAD framing) a day for a worthy cause and the second group was inquired if they like to pay aggregate amount of 300$ a year. The studies show that PAD framing was significantly higher than aggregate framing [18]. Two of important factors in PAD that have been discovered are as follows [18]:

1-PAD provides more attraction for transactions involving losses than gains. 2-In low cost transactions PAD is effective, but in high cost transactions the impact is vice versa because of hedonic editing effects (see, [3]) (e.g., 3$ a day is what I spend on coffee each day but I don't really spend 30$ each day on anything. ([18], p. 386).

PAD Strategy can be applied in the Idea Bank when experts are asked to contribute their ideas regarding their specialty. An expert- during his professional life- has probably tackled a given problem many times and can contribute an idea (i.e., equal to a small daily expense) more easily and faster than a person, professionally unfamiliar with the same problem (i.e., for experts in unrelated fields it works like a high cost transaction). Therefore this can be claimed that the PAD strategy is the best possible method and will be of great value for the municipality.

H4: Reframing experts' cooperation to a series of ongoing ideas strengthens the attractiveness of cooperation.

This is investigated in the fourth study.
3. METHOD

3.1 Participants

The participants were 202 experts (139 male and 63 female / 141 employees and 51 employers). Experts in our idea bank consist of different groups of dons, lawyers, engineers, managers, hygienists, treatment experts, consultants, and social experts. They all had contributed in the idea bank before. Ages ranged from 25 to 67, with a mean of 39.47 years. The population was the civic experts in Tehran with at least BS degree.

3.2 Research design and procedure

The questionnaires were distributed among experts. This was mostly done by meeting the experts in their offices and handing them the questionnaires. In other cases the questionnaires were emailed or posted. Five experiments performed in two phases. In the first phase participants answered half of the questions and after two months the rest of the questions were answered.

Since understanding the questions was necessary for the respondents, therefore we performed an interview with some of them after each experiment. These interviews authenticated the reliability and stability of responds of the experiments. Furthermore we needed to find out the expert's reasoning after the test. We tested the questionnaires 3 times in the pre-test group and the result of the final testing was approximately the same as the result of the third test in the pre-test group. Also one question appeared at the end of the experimental instrument which demanded: "How clear were the questions in this questionnaire?" to check the clarity of the experiment [21] responds recorded on a 1 (very unclear) to 9 (very clear) scale. The mean response obtained in first pre-test group was 5.83, by modifying some of questions a new mean equal to 8.21 achieved in the last pre-test group. Another technique we applied for validation of the questionnaires was acquiring the opinions of five academic professors and applying the required modifications.

Several studies have supported the validity, and reliability and internal consistency of the framing and mental accounting problems [6], [22], [23]. According to the literature review some were used in current study like donation program in the fourth study and the others are designed retrieving from previous studies by considering the variation of the idea bank outcomes. They were used to test, the validity, existence and effectiveness of framing effects in the idea bank. In the studies 1, 2, and 4 we asked subjects to indicate their likeliness on a five point respond scale, on which to respond (1="very low", 5="very much"). And in studies 3, subjects were asked to respond double choice questions.

4. MAIN RESEARCHES

In this section framing effects that have been discussed in the literature will be investigated. According to the order of hypotheses, each study will be discussed.

4.1 Study 1

The objective of presenting this study is to investigate the existence of sunk cost in the idea bank. In prior researches question 1 (which is about the information related to the purchase of a basketball match ticket) had been used in order to examine the sunk cost in decisions and outcomes indicate appearance of sunk cost. It is explained for the second time to investigate its relationship with the second question. The format of the second question is similar to the first question but contains outcomes connected to the idea bank, subjects who responded to question 1 answered question 2, two months later based on a code included in their questionnaires.

Questions: 1-imagine you have booked a ticket to a basketball game for $50, which is not refundable. Suppose there is a snowstorm on the day of the game which makes the driving dangerous. How eager you are to go there?
2-imagine you have got a concert ticket of your favourite singer in VIP part from idea bank as your requested award for your accepted idea, a week ago. But according to the weather forecasts, there will be a storm at the night of the concert and it is dangerous to drive. How likely you are to participate in this event? (Note that this ticket could cost you $50 if you wanted to buy it yourself)

**Results and Discussion**

The results of chi-squared test for both questions (Table I) proves that at 95% confidence level (P-Value<0.05), the proportion of choices are not equal. The outcomes of the correlation between these two questions (P-Value<0.05) evidences the positive relationship between them. In first and second questions, almost the answers' trends were upward (M=3.06 and M=3.4), but this trend in second question had a more upward trend. As a result, by taking both of these results into consideration, the existence of sunk cost in the idea bank would be verified.

The interesting point in this study is the higher mean of responds in second question in comparison with first one. So it might be concluded that the members' enthusiasm to avoid the loss impression in the idea bank (closure of a mental account containing loss of missing a reward in the idea bank), creates a stronger sunk cost, compared with closing of a mental account containing loss out of the idea bank. In other words ideation develops a higher mental value in comparison with paying money; this is regarded as one of the implications of this article.

One of the limitations of this study is that the specified outcome is related to a service (i.e., an event like concert), because if the reward would be a physical good, it would be possible to make less eagerness. Therefore we suggest the investigation of a combination of rewards inclusive of both service and good for future studies.

Table I: Descriptive Statistics of Study 1.

<table>
<thead>
<tr>
<th>Coefficient Correlation (P-Value)</th>
<th>Chi-Square (P-Value)</th>
<th>Percent(N)</th>
<th>Options</th>
<th>Mean &amp; Std. Deviation</th>
<th>STUDY 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.470 (0.00)</td>
<td>30.72 (0.00)</td>
<td>10% (21)</td>
<td>Very Low</td>
<td>M=3.06 S=1.22</td>
<td>Study1_1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>28% (60)</td>
<td>Low</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>20% (40)</td>
<td>Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30% (56)</td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>12% (25)</td>
<td>Very High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38.20 (0.00)</td>
<td>8% (17)</td>
<td>Very Low</td>
<td>M=3.40 S=1.18</td>
<td>Study1_2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13% (26)</td>
<td>Low</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28% (57)</td>
<td>Medium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>31% (63)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19% (39)</td>
<td>Very High</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**4.2 Study 2**

This question is aimed to find out the effectiveness of bundled and unbundled rewards in the idea bank in two states. In the first state problems and rewards are presented in unbundled form and the person is said how much benefit (how many dollars) will achieve for each of the expenses he/she pays (the idea for a specified problem). On the other side in second state (Table 4) problems and rewards are present in bundle form. Meanwhile except indicated...
tables that each is presents with two months lag, other information (including, problem statement and two questions in each state) are repeated exactly.

**Problem statement:**
Imagine $10000 is assigned to solve 5 problems of one of the twenty two civic districts of Tehran as indicated below:

1 - Residents’ problems about increasing population of noxious animals
2 - Residents’ problems about the retrofitting of the old structures in the city
3 - Reduction in the amount of resident's general reading.
4 - Lighting deficiency at night
5 - High ways’ sound pollution for the districts’ residents

Table II: Unbundling cost and benefit in the idea bank.

<table>
<thead>
<tr>
<th>Problems (state 1)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total Award $10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of award for each accepted idea</td>
<td>$1000</td>
<td>$2000</td>
<td>$2000</td>
<td>$3000</td>
<td>$2000</td>
<td>$10000</td>
</tr>
</tbody>
</table>

Table III: bundling cost and benefit of transaction in the idea bank.

<table>
<thead>
<tr>
<th>Problems (state 2)</th>
<th>Total Award $10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td></td>
</tr>
</tbody>
</table>

(Please note that between problems 1-5, there is no priority in giving your idea)

**Questions:**
If the above state is the way that you receive your $10000 award, please answer two questions below:
1 - How eager you are to solve the problems?
2 - If you had effectively succeeded to solve the problems and your Idea had been accepted by the municipality, but after that the idea bank could not afford the whole award (only $8000 possible to be paid), by taking the dissatisfaction resulted from not getting the whole promised reward, to what extent you are eager to continue presenting idea and participating in the idea bank in future?

The purpose of first and second questions was to indicate the propensity to participation and receipt.

**Results and Discussion**

In Table IV the primary information in given. The chi-square test results in all four questions show that at the %95 confidence level the proportion of choices in this examination are not equal. In question 1 from the first state the trend of responds is downward (M=2.36). Question 2of first state implies the downward trend (M=2.52). Therefore when offering expense and reward in the idea bank is done on an unbundled base, the participation propensity would be less and consume pressure increases to the extent that not paying the whole specified reward, the majority of members prefer to have less eagerness for cooperation with the idea bank in future.
Table IV: Descriptive Statistics of Study 2.

<table>
<thead>
<tr>
<th>STUDY 2</th>
<th>Mean &amp; Std. Deviation</th>
<th>Chi-Square (P-Value)</th>
<th>Percent(N)</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>State 1-</td>
<td>M=2.36 S=1.24</td>
<td>53.99 (0.00)</td>
<td>29% (58)</td>
<td>Very Low</td>
</tr>
<tr>
<td>question 1</td>
<td></td>
<td></td>
<td>35% (71)</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14% (29)</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15% (30)</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7% (14)</td>
<td>Very High</td>
</tr>
<tr>
<td>State 1-</td>
<td>M=2.52 S=1.28</td>
<td>60.87 (0.00)</td>
<td>22% (22)</td>
<td>Very Low</td>
</tr>
<tr>
<td>question 2</td>
<td></td>
<td></td>
<td>41% (30)</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12% (24)</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15% (82)</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11% (44)</td>
<td>Very High</td>
</tr>
<tr>
<td>State 2-</td>
<td>M=3.87 S=1.15</td>
<td>106.27 (0.00)</td>
<td>6% (67)</td>
<td>Very Low</td>
</tr>
<tr>
<td>question 1</td>
<td></td>
<td></td>
<td>8% (84)</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11% (22)</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>42% (16)</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>33% (13)</td>
<td>Very High</td>
</tr>
<tr>
<td>State 2-</td>
<td>M=3.61 S=1.25</td>
<td>67.55 (0.00)</td>
<td>9% (18)</td>
<td>Very Low</td>
</tr>
<tr>
<td>question 2</td>
<td></td>
<td></td>
<td>13% (26)</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12% (25)</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>40% (81)</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>26% (52)</td>
<td>Very High</td>
</tr>
</tbody>
</table>

In first question of second state the trend of responds is upward (M=3.87) and also the same trend could seen in question 2 of second state (M=3.61). Hence when incurring the expense and earning happen in bundled way propensity for participation would be higher and the pressure for consumption will be less.

Table V: Coefficient Correlations.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficient Correlation (P-Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>State 1-question 1</td>
</tr>
<tr>
<td>State 1-question 1</td>
<td>1</td>
</tr>
<tr>
<td>State 1-question 2</td>
<td>+0.39(0.00)</td>
</tr>
<tr>
<td>State 2-question 1</td>
<td>-0.45(0.00)</td>
</tr>
<tr>
<td>State 2-question 2</td>
<td>0.60(0.00)</td>
</tr>
</tbody>
</table>

In Table V the results of correlation test in four questions are shown. These results indicate in confidence level of %95 (P-Value<0.05), between questions 1 and 2 in both states, a positive and meaningful relationship exists. Therefore in both states between the propensity for participation and propensity for consumption a direct relationship exists; but between similar questions 1 in both states and 2 in both states, a meaningful and counter relationship. This result also confirms the conflict in members decision making, when the problem is given once bundled and next time unbundled.

These outcomes are consistent with [6] findings but the difference is that in their experiment the expense was monetary and paid for skiing, but here the expense is the idea for getting reward that is monetary, so spending it depends on them. The pressure arising
from the propensity for receiving the reward, somehow strengthens the sunk cost effect, 
because closing of a loss containing account in person's mind causes dissatisfaction.
Based on this study's findings it is suggested to attract more participation for idea reception 
on one hand and to reduce the experts' dissatisfaction in case of not providing the whole 
expected reward on the other hand, it would be better to offer the problems and related 
rewards as bundled.

4.3 Study 3

Investigation of the pseudo certainty effect is the purpose of this study. The question is 
manipulated in a way that is inclusive of the bank's outcomes.
The first question of this study contains two stages, first, idea presentation and assessment, 
second, receipt of reward.

Questions:
1- In the first stage of presenting your idea (i.e. before the first idea evaluation), There is 3/4 
probability that you may not enter to second stage, so there is no award and there is 1/4 
probability that you may successfully enter to the second stage.
   The idea bank in the second stage has designed the reward in two different programs. 
The first program is without gamble and the second one contains gamble.
Which of the two municipality's award programs would you favor as the owner of the 
accepted idea?
   Program A: I don't take part in idea bank's gambling so I certainly gain 3 kinds of my 
favorite awards
   Program B: I take part in idea bank's gambling and by 4/5probability I may win 5 kinds of 
my favorite awards
   (Please note that first, the probabilities 3/4 and 1/4 are counted based on scientific estimation 
according to the previous rate of idea success and failure in the idea bank second, your 
choice must be made before presenting your idea, i.e., before the result of the first stage is 
recognized. third, the kind of prizes in both programs is according to your choice among the 
idea bank's award portfolios).
2 - The idea bank intends to present two different programs in gamble form for you as your 
requested award in program C with a probability equal to 1/4, you will get three kinds of 
rewards and in program D with 1/5 probability you would select 5 kinds of your favourite 
rewards.
   Which of the prize program, meaning C or D, would you 
favour in idea bank?
Program C: There is 1/4probability that you may gain 3 of your favourite awards
Program D: There is 1/5probability that you may gain 5 of your favourite awards
   (Please note that the kind of prizes in both programs is according to the expert's choice 
among the idea bank's award portfolios)

Results and Discussion

The results of Chi-Square test (P-Value<0.05) in Table VI shows that there is an 
independence between the respond in each of the questions. The first question contains 
Pseudo certainty effect of framing but the second question lacks framing effect and only has 
been asked as a control question. As it was mentioned earlier, Pseudo certainty effect has 
got two stages. In the first stage the problem will be manipulated to get risky (in this question 
1/4 and 3/4) and negative (you won't enter to) outcomes.
According to risky frame most members behave in a risk-taking manner, therefore they 
would have a less risk perception and the prospect of three kinds of rewards in the second 
stage seems more attractive which looks like an illusion that directs the person to the second 
stage. In this stage the problem is manipulated in a way that would be inclusive of certain 
and positive outcomes. This option based on risky frame, has got a higher and more
attractive subjective value, this is why the subject will choose the certain option between risky and certain choice.

Table VI: Frequency Distribution of Study4.

<table>
<thead>
<tr>
<th>STUDY4</th>
<th>Options</th>
<th>Percent(N)</th>
<th>Chi-Square(P-Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study 4_1</td>
<td>Variable1</td>
<td>66%(134)</td>
<td>21.56 (0.00)</td>
</tr>
<tr>
<td></td>
<td>Variable2</td>
<td>34%(68)</td>
<td></td>
</tr>
<tr>
<td>Study 4_2</td>
<td>Variable3</td>
<td>29%(58)</td>
<td>36.61 (0.00)</td>
</tr>
<tr>
<td></td>
<td>Variable4</td>
<td>71%(144)</td>
<td></td>
</tr>
</tbody>
</table>

In this study programs A and C in terms of the consequence are equal, because the possibility of 1/4 for winning three prizes is exactly program C in the second question. Program B offers 1/4*4/5=1/5 chance, that it is exactly the same as program D in the second question. Nevertheless, these results indicate that %66 of members chose program A and only 29% selected programs C. this indicates the occurrence of conflict in people's choices, which prove that the effect of frame has been applied.

In an interview with the subjects who had chosen program D (71% of subjects) after collecting and analyzing the questionnaires' information, the experts stated that by only taking 5% (1/4-1/5=0.5) more risk (in second question) they can raise their awards up to 66% (5-3/3=.66), which is a logical reasoning, but when they saw their responds to the first question and comparison was possible for them, they were really astonished.

The results of Table VII shows that only 7% of people who chose option A in question 1, selected option C in question 2, therefore had a consistent decision, and from 71% of respondents who chose option D, 59% selected option A, the same people who had an inconsistent decision in 2 questions. Thus from the sum of these reasons, it can be admitted that by using pseudo certainty effect, around (59% *66%=0.39) 39% of reward costs might be decreased and by taking the costly rewards the experts demand, this amount of reduction could be very cost-effective.

Table VII: Study_1 × Study_2 Cross Tabulation.

<table>
<thead>
<tr>
<th>Study 4_2</th>
<th>Variable3</th>
<th>Variable4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable1</td>
<td>7%(14)</td>
<td>59%(120)</td>
<td>66%(134)</td>
</tr>
<tr>
<td>Variable2</td>
<td>22%(44)</td>
<td>12%(24)</td>
<td>34%(68)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>29%(58)</strong></td>
<td><strong>71%(144)</strong></td>
<td><strong>100%(202)</strong></td>
</tr>
</tbody>
</table>

The quantitative measured amount of reduction level in the expenses is one of the significant implications of this article, for example to our knowledge in other researches of framing area the amount of its effects had not been measured in a tangible manner before.

Interestingly pseudo certainty method works even for experts that have been working in idea bank for a long period of time. This claim is arisen from the experts' cooperation experience in the idea bank during their operation and always a slightly more or less of this rate of expense reduction has been recorded.

4.4 Study 4

The purpose of this study is the investigation of PAD function in the idea bank. In this study, it is assumed that it might be possible to provide the establishment for long term cooperation with experts by designing issues weekly or monthly and offering the award for the each time, just as prorating a major expense to smaller parts to acquire benefit. The important point in using this technique is the similarity of field problem with experts' specialized area. It would
be worth mentioning that questions 1 and 2 in stage 1 and the third question have been examined two months later.

**Questions:**
1 - In your opinion, to what degree will you be motivated to have ongoing cooperation with the idea bank, in a way that you get the expressed problems on a weekly or monthly basis and related to your specialized field in the idea bank and for which you present an acceptable area. In addition for each time of idea presentation and assessment from bank, you will receive reward:
2 - if you averagely donate $300 per years to a worthy cause, how much you prefer to donate 85 cents per day over donate $300 once entirely?
3 - if you averagely donate $300 per years to a worthy cause, how much you prefer to donate $300 once entirely over to donate 85 cents per day?

**Results and Discussion**

The result of chi-square (P-Value<0.05) in Table VIII shows that the proportion of choices is not equal. Mean of responds in first question (M=3.77) represents the upward trend of answers which means most of respondents believe that the weekly and monthly ideation with respect to their specialized fields, cause more motivation for continues cooperation in the idea bank. Also second question results indicate the upward trend that means most of experts prefer instead of paying the whole $300 at once, 85 cents for each single day (that is a sign of the effectiveness of PAD strategy). Besides, results of correlation in table IX represents the direct relationship between questions 1 and 2. The result of mean in question 3 (M=2.64) is an evidence of downward trend and less propensity of them for paying $300 at once instead of paying 85 cents daily. In addition between question 3 and questions 1 & 2 an inverse relationship is established (see Table IX) this set of results can make the usage of PAD in the idea bank acceptable.

**Table VIII: Descriptive Statistics of the Study4.**

<table>
<thead>
<tr>
<th>STUDY4</th>
<th>Mean &amp;Std. Deviation</th>
<th>Options</th>
<th>Percent(N)</th>
<th>Chi-Square (P-Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study 4_1</td>
<td>M=3.77 S=1.20</td>
<td>Very Low</td>
<td>6%(13)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>10%(21)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>16%(33)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>33%(67)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Very High</td>
<td>34%(68)</td>
<td></td>
</tr>
<tr>
<td>Study 4_2</td>
<td>M=3.37 S=1.26</td>
<td>Very Low</td>
<td>11%(22)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>14%(28)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>23%(46)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>32%(65)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Very High</td>
<td>21%(42)</td>
<td></td>
</tr>
<tr>
<td>Study 4_3</td>
<td>M=2.64 S=1.19</td>
<td>Very Low</td>
<td>16%(32)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>39%(78)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>20%(41)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>16%(33)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Very High</td>
<td>9%(18)</td>
<td></td>
</tr>
</tbody>
</table>

What makes PAD more effective is that, the service provider (i.e., here the idea bank agents) must be able to recognize the stockholders’ (i.e., experts) needs and wants otherwise there
is no motivation for the expert to analyze and comparison the cost and benefit of the transaction.

Table IX: Coefficient Correlation of Study 5.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Study 5_1</th>
<th>Study 5_2</th>
<th>Study 5_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study 5_1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study 5_2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study 5_3</td>
<td>-0.43(0.00)</td>
<td>-0.70(0.00)</td>
<td></td>
</tr>
</tbody>
</table>

Using this strategy in the idea bank is one of the important implications of this article. In no other articles it is seen to use this strategy except for prorating large monetary expenses to smaller parts for encouraging the propensity to purchase or doing a task. The usage of this strategy in other nonmonetary areas could be regarded a potential subject for future studies.

The main limitation of the present study was the restricted number of experts in the idea bank. Since the purpose of this study was to investigate the framing effects in the idea bank and the specified sample must have been chosen from the idea bank's experts, we were confronted with the limited number of experts. That's why we had to implement questionnaire in two stages with two months lag. Otherwise the subject may understand the manipulation trick that had been used and in this case the results of this study would not be reliable. In this study a limited number of framing effects have been investigated. By taking the results of the study into consideration, it is evident that some of the primary theoretical constructs of framing area and mental accounting could be employed in the idea bank; therefore it is possible to be able also to investigate other constructs of this area in the idea bank and similar systems in organizations. This item is one of the other limitations of the present study which is equipped with good potential for future studies.

5. CONCLUSION

In this paper we investigated application of framing effects and mental accounting across four studies. We have shown that application of sunk cost, bundle/unbundle framing of outcomes and Penny-a-day strategy in generating ideas in the idea bank like any monetary transaction in the real world make a subjective account for the expert. This account would have similar features as a account in the mental accounting domain. This is investigated respectively in the study 1, 2 and 4. Finally in the Study 3 we showed that how Pseudo certainty effect could reduce idea bank's awards expenses even the amount of reduction illustrated quantitatively. We believe our work contributes to a more Innovative view at framing effects and its psychological effects on effectiveness of expert's decision making in the idea bank also the results of this study might be applied similarly in enhancing the productivity of the any suggestion systems in an organizations or even in contributing of experts in social networks.

ACKNOWLEDGEMENT

We thank Joun Gourvill for many helpful comments.
REFERENCES

Notes for Contributors

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It is required to use Arial font. Margins: 25 mm all around (all pages).

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The author's name(s) follows and is also centred on the page (font size 12 pt). A blank line is required between the title and the author's name(s). Last names should be spelled out in full and succeeded by author's initials. The author's affiliation, complete mailing address, and e-mail address (all in font size 11 pt) are provided below. Phone and fax numbers do not appear.

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Key Words

The author should provide a list of three to five key words that clearly describe the subject matter of the paper.