Productivity
&
Productivity Measurement Systems

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Topics From Last Class
Discussion
Standards for Scientific Management

• Integration
• Scope
• Time
• Cost
• Quality

• Human Resource
• Communications
• Risk
• Procurement
• Stakeholder
• Health Safety & Env.
• Other Mgmt Issues

ISO 9001:2008
ISO 14001:2004
OHSAS 18001:2007
BIS 15883

PROCESS STANDARD

Management Approach
Role of Management Standards?

- **Time Management – BIS 15883**
- **ISO 9001:2008**
- **OHSAS 18001:2007**
- **ISO 14001:2004**

Planning Levels

- **Master Plan**
  - Major Milestones -> Quarters
  - Key resources
- **Macro Plan**
  - Activity Completion -> Monthly/Weekly
  - Quantity Targets
  - Overall Resource Requirements
- **Micro Plan**
  - Activity Completion -> Daily/Weekly
  - Quantity/Location Targets
  - Detailed Resource Requirements
- **Execution**
Monitoring Levels

Master Plan
Macro Plan
Micro Plan
Execution

Monthly Reports & EVM Parameters.
Weekly Reports & Activity Targets
Productivity Trends
Daily Progress Reports
Productivity Measurement & Improvement. Catch-up Plan

Travel Example

Productivity in Construction

Corporate Level
Regional Level
Project Level
Work-Package Level
Operation Level
What is Productivity?

- OUTPUT / INPUT

- WHAT IS OUTPUT & INPUT?

Productivity Models

$$\text{TFP} = \frac{\text{TOTAL OUTPUT}}{\text{LABOR + MATERIALS + EQUIPMENT + ENERGY + CAPITAL}}$$

- TOO BROAD A MEASURE FOR MICRO LEVEL

- WE ARE FOCUSING ON PRODUCTIVITY ON THE PROJECT SITE

- PRODUCTIVITY THAT CAN BE CONTROLLED BY THE SITE ENGINEER / CONSTRUCTION MANAGER
MORE SPECIFIC MODEL

\[
\text{PROD} = \frac{\text{OUTPUT}}{\text{LABOUR} + \text{MATERIALS} + \text{EQUIPMENT}}
\]

This will give a reasonable measurement of Output & Input for Absolute Productivity Measurement

BUT IF OUR PRIMARY AIM IS PRODUCTIVITY IMPROVEMENT

INPUTS MATERIALS & EQUIPMENT ARE LESS VARIABLE

LABOUR IS HIGHLY VARIABLE & PRODUCTIVITY CAN BE RELIABLY BENCHMARKED BASED ON LABOUR

---

OUR MODEL

\[
\text{PROD} = \frac{\text{OUTPUT}}{\text{LABOUR (HOURS) (COST)}}
\]

OR

\[
\frac{\text{LABOUR (HOURS) (COST)}}{\text{OUTPUT}}
\]

BASIC FACTORS FOR A PRODUCTIVITY MEASUREMENT SYSTEM ARE

LABOUR HRS
&
QUANTITY OF WORK DONE
Formal Productivity Measurement

- Planning and control systems (*Based on Primavera.*)
  - Data collected from entire project
  - Delay in identification of problems

- Productivity Measurement systems
  - Focus on critical activities
  - Measures Labour/Material/Equipment
  - Less Delay in identification of problems.

- Both systems require organizational effort

Productivity Analysis Process

- The overall process of productivity measurement

- Selected Activity in Progress
  - Workhours
  - Quantities
  - Productivity Calculations
    - Performance Evaluation
    - Workhour Forecast
    - Analysis of Trends
Step-1: Workhours Measurement

Selected Activity in Progress

Workhours  Quantities

Productivity Calculations

Performance Evaluation  Workhour Forecast  Analysis of Trends

Assume Formwork Operations

The workhour distribution may be,

Direct crew workhours or Total Crew Hours?

Assume measuring only the direct crew workhours, since including all items makes the data more difficult to interpret.
Step-2: Quantities Measurement

- Selected Activity in Progress
  - Workhours
  - Quantities
  - Productivity Calculations
    - Performance Evaluation
    - Workhour Forecast
    - Analysis of Trends

MEASUREMENT OF QUANTITIES

- Units Complete
- Percentage Complete
- Level of Effort
- Incremental Milestone
Performance is the comparison of actual productivity to what was expected

- Performance Factors
- Earned Value
- Forecasting

**PERFORMANCE FACTOR =**

\[
\frac{\text{ACTUAL UNIT RATE}}{\text{PLANNED OR ESTIMATED UNIT RATE}}
\]

Can it be inverse?

VALUE > 1 SHOWS PERFORMANCE BETTER THAN EXPECTED

VALUE < 1 SHOWS LESS THAN DESIRED PERFORMANCE
Productivity Monitoring - DPR

Productivity Reporting

- DAILY
- WEEKLY – PERIODICAL
- CUMULATIVE
DAILY CALCULATIONS

- **Advantages:**
  - Immediate Feedback
  - Specific Identification of causes
  - Order of Magnitude of a Problem

- **Disadvantages**
  - Daily Calculations
  - Difficult to explain all variations

- When & Where would you use it?
PERIODIC CALCULATIONS

- **Advantages:**
  - Fewer Calculations
  - Less Fluctuation in data

- **Disadvantages**
  - Not timely if period is too long
  - Daily variations are hidden
  - Limited data points to base conclusions
  - Cannot identify most causes

- When & Where would you use it?

CUMULATIVE CALCULATIONS

- **Advantages:**
  - Closely relates to cost and profitability
  - Critique of overall progress
  - Forecasting probable outcome
  - Suitable for Upper Management

- **Disadvantages**
  - Insensitive to daily, periodic variations

- When & Where would you use it?
Target Not Met  Action Taken?

Increase  
Manpower, 
Shifts & Resources

Target Met  OK ??

Project Influences on Productivity

MANPOWER UTILIZATION  PRODUCTION PROCEDURES  QA/QC PROCEDURES

EQUIPMENT UTILIZATION

MATERIAL UTILIZATION

CONSTRUCTION METHODS

LABOUR PRODUCTIVITY

TOTAL FACTOR PRODUCTIVITY

OPERATING EFFECTIVENESS

NON-MANUAL MANPOWER UTILISATION
Factors That Improve Productivity

1. Learning or Experience Curves Improvement
2. Educational and Training Programs
3. Safety Programs
4. Innovative Materials and Equipment
5. Prefabrication of Building Components
6. Critical Path Method for Planning, Scheduling and Control

7. Value Engineering
8. Precast and Prestressing Concrete
9. Computerization of Business and Engineering Activities
10. Worker Motivation Programs
11. Constructability Review of Design
12. Standardization
13. Preplanning of Activities
14. Short Interval Scheduling
15. Purchasing Practices
16. Use of Scale Models
17. Competition between Crews, Areas or Shifts
18. Incentives in Contract
19. Effective Utilization of Subcontractors
20. Enough Tools in Working Order
21. Time and Motion Studies to Improve Efficiency, Reduce Fatigue, and Work Smarter
22. Good Supervision

Factors That Have An Adverse Effect on Productivity

1. Overtime and / or Fatigue
2. Errors and Omissions in Plans and Specifications
3. Multitude of Change Orders
4. Design Complexity
5. Design Completeness
6. Stacking of Trades
7. Dilution of Supervision
8. Reassignment of Manpower from Task to Task
9. Material Location - Above Ground Level
   - Above Floor Level
10. Adverse Temperature or Weather
11. Inadequate Lighting
12. Ground Water Level
13. Regulations of Various Types
14. High Absenteeism
15. High Turnover
16. Material Shortages

17. High Accident Rate
18. Jurisdictional Disputes
20. Availability of Skilled Labor
20. Attitude of the Workforce
22. Crew Size and Composition
23. Economic Conditions and Level of Unemployment
24. Size and Duration of Project
25. Timeliness of Decisions
26. Impractical QA/QC Tolerances
27. Uncontrolled Breaks
28. Time of Day and Day of Week
Productivity Assessment

- Assess where time is lost on a project.
  - Are people spending time on direct work?
  - Are they idle for a significant duration
  - Is there too much traveling
  - What proportion of the site activity is directed towards contributory work vs non-contributory work

Conventional Framework - Sources of Lost Time

- Idle Time
- Rework
- Lost Time
- Excessive Travel
- Slow Work
Idle Time

- Late Starts & Early Quits
- Waiting for Inspection
- Availability of tools, materials & equipment
- Accidents
- Mobilization & Re-mobilisation

Excessive Travel

- Logistics of tools and materials
- Paperwork
- Layout
Slow Work

- Low craftsman skills
- Fatigue
- Adverse weather

Rework

- Engineering Errors
- Inaccurate drawings
- Misleading technical instructions
Limitation!!!

Activity based View

Lost-Time .vs. Muda (waste)

• Lean identifies seven forms of waste that can be summarized by the mnemonic TWO DIME. It stands for:
  ➢ Transport
  ➢ Waiting
  ➢ Overproduction
  ➢ Defects
  ➢ Inventory
  ➢ Motion
  ➢ Excess processing
PRODUCTIVITY MEASUREMENT SYSTEM

Selected Activity in Progress

- Work Hours
- Quantities (Based on Daily progress Report)

Productivity Calculations

Performance Evaluation

Step-2: Quantities Measurement

Selected Activity in Progress

- Workhours
- Quantities

Productivity Calculations

- Performance Evaluation
- Workhour Forecast
- Analysis of Trends
Measurement Methods

- Units complete
- Percent complete
- Level of Effort
- Incremental Milestones
- Start / Finish Percentages

1. Units Complete

Criteria for application
- Well-defined and clear scope
- Relatively only few subtasks
- Short duration for completion of each unit of output
- Single craft or trade

Examples
- Piling works
- Installation of fixtures (sanitary, electrical, HVAC, etc.,)
- Cable pulling (thro’ conduits)
Advantages
- Most detailed and accurate
- Does not rely on subjective opinions or evaluations (on outputs)
- Claimed output can be readily and easily verified by counting or elementary math

Disadvantages
- Costly and inaccurate data collection, if misapplied

Comment
- It can be applied better for the finishing works rather than the core construction activities

2. Percent Complete

Criteria
- Activities which involves areas rather than single units
- Relatively minor tasks where reasonably accurate estimates can be made
- Only few subtasks

Examples
- Painting works, Floor finishing
- Lighting systems

Advantages
- Simple, Inexpensive and Quick

Disadvantages
- Can be very inaccurate and misleading
3. Level of Effort

Criteria
- Activities involving overlapping subtasks
- Subtasks must be measurable or their status must be defined
- Best suited where there is a large number of similar items.
- Duration of the work is long
- When there is a need to account for work partially completed

Examples
- Concrete, formworks, etc.,
- Structural steel works
- HVAC ducts, Cable trays, Conduit, Piping works, etc.,

Advantages
- Greater detail and objectivity than simply estimating how work was done
- Less expensive (for good accuracy) than counting or measuring the units completed
- Best in case of activities involving multi trades or crafts

Disadvantages
- More components (subtasks) to measure than simply estimating the percent complete
Example – 1

Assume Fabrication, Installation & Inspection of Hanger rods

<table>
<thead>
<tr>
<th>Subtask</th>
<th>Unit of Measure</th>
<th>Rule of Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabrication</td>
<td>each</td>
<td>0.40</td>
</tr>
<tr>
<td>Installation</td>
<td>each</td>
<td>0.50</td>
</tr>
<tr>
<td>Preservice inspection</td>
<td>each</td>
<td>0.10</td>
</tr>
<tr>
<td>Total task</td>
<td>each</td>
<td>1.00</td>
</tr>
</tbody>
</table>

To date quantities: 366 Hangers fabricated, 185 Hangers installed, 41 Hangers accepted

Calculate cumulative quantity ???

Solution

<table>
<thead>
<tr>
<th>Subtask</th>
<th>Unit of Measure</th>
<th>Rule of Credit</th>
<th>Qty Completed</th>
<th>Cum. Qty (1 x 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabrication</td>
<td>each</td>
<td>0.40</td>
<td>366</td>
<td>146.40</td>
</tr>
<tr>
<td>Installation</td>
<td>each</td>
<td>0.50</td>
<td>185</td>
<td>92.50</td>
</tr>
<tr>
<td>Preservice inspection</td>
<td>each</td>
<td>0.10</td>
<td>41</td>
<td>4.10</td>
</tr>
<tr>
<td>Total task</td>
<td>each</td>
<td>1.00</td>
<td>243</td>
<td></td>
</tr>
</tbody>
</table>

Cumulative quantity = 243 Hangers
Example – 2

<table>
<thead>
<tr>
<th>Subtask</th>
<th>Unit of Measure</th>
<th>Rule of Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erecting</td>
<td>Individual pieces</td>
<td>0.50</td>
</tr>
<tr>
<td>Bolting (bolt-up)</td>
<td>Individual pieces</td>
<td>0.25</td>
</tr>
<tr>
<td>Plumbing</td>
<td>Pieces grouped by tier</td>
<td>0.15</td>
</tr>
<tr>
<td>Tightening (torque bolts)</td>
<td>Pieces grouped by tier</td>
<td>0.10</td>
</tr>
<tr>
<td><strong>Total task</strong></td>
<td>piece</td>
<td><strong>1.00</strong></td>
</tr>
</tbody>
</table>

To date quantities: 439 pieces erected, 387 pieces bolted, 310 pieces plumbed, 193 pieces torqued

**Calculate cumulative quantity ???**

<table>
<thead>
<tr>
<th>Subtask</th>
<th>Unit of Measure</th>
<th>Rule of Credit (1)</th>
<th>Qty Completed (2)</th>
<th>Cum. Qty (1 x 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erecting</td>
<td>Individual pieces</td>
<td>0.50</td>
<td>439</td>
<td>219.50</td>
</tr>
<tr>
<td>Bolting (bolt-up)</td>
<td>Individual pieces</td>
<td>0.25</td>
<td>387</td>
<td>96.75</td>
</tr>
<tr>
<td>Plumbing</td>
<td>Pieces grouped by tier</td>
<td>0.15</td>
<td>310</td>
<td>46.50</td>
</tr>
<tr>
<td>Tightening (torque bolts)</td>
<td>Pieces grouped by tier</td>
<td>0.10</td>
<td>193</td>
<td>19.30</td>
</tr>
<tr>
<td><strong>Total task</strong></td>
<td>Piece</td>
<td><strong>1.00</strong></td>
<td></td>
<td><strong>382</strong></td>
</tr>
</tbody>
</table>

Cumulative quantity = 382 Pieces
4. Incremental Milestones

Criteria
- Many activities involving many subtasks and trades
- Large and complex projects with lot of activities, making measurement of each activity time consuming

Examples
- Work completion upto plinth level, ground floor roof, first floor roof, etc.,
- Internal electrification: block 1, block 2, etc.,

Advantages
- Easy, Quick and less time consuming for large projects

Disadvantages
- Can be very inaccurate and misleading

Which Measurement Method ???

Criteria for selecting a measurement method
- Simplicity Vs Accuracy
- Complexity of the Activity and Project
- Scope of the Activity and Project
- Construction method
Step-2: Quantities Measurement

Selected Activity in Progress

Workhours

Quantities

Productivity Calculations

Performance Evaluation

Workhour Forecast

Analysis of Trends

EARNED VALUE

Earned Value is a technique for evaluating the percent complete of a group of activities

Projects are typically divided into work-packages – Each work-package will have a number of activities
Measuring % Complete

Installed Quantity
Estimated Quantity

For a single activity – Or group of activities where Quantity measurements are the same.

WORKHOURS / RUPEES

Only Resources that are common to all activities

THE EARNED VALUE CONCEPT USES MEASURES % COMPLETE BASED ON THESE TWO RESOURCES AS THEY ARE THE ONLY ONES COMMON TO ALL ACTIVITIES
INFORMATION NEEDED

- Initial estimated unit rate
- Current quantity estimate
- Quantities installed to date

% Complete Calculation Using Earned Workhours

<table>
<thead>
<tr>
<th>ACCOUNT</th>
<th>EST. UNIT RATE</th>
<th>CUR QUAN EST</th>
<th>TOT. EARN WH</th>
<th>QUAN TO DATE</th>
<th>EARN WH TO DATE</th>
<th>% COMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Bore Piping</td>
<td>1.27</td>
<td>1063</td>
<td>1,350</td>
<td>197</td>
<td>250</td>
<td>18.5</td>
</tr>
<tr>
<td>Large Bore Piping</td>
<td>1.02</td>
<td>10,000</td>
<td>10,200</td>
<td>701</td>
<td>715</td>
<td>7.0</td>
</tr>
<tr>
<td>All Piping (Control)</td>
<td></td>
<td></td>
<td>11,550</td>
<td></td>
<td>956</td>
<td></td>
</tr>
</tbody>
</table>

8/15/2017
% Complete Calculation Using Earned Workhours

<table>
<thead>
<tr>
<th>ACCOUNT</th>
<th>EST. UNIT RATE</th>
<th>CUR QUAN EST</th>
<th>TOT. EARN WH</th>
<th>QUAN TO DATE</th>
<th>EARN WH TO DATE</th>
<th>% COMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Bore Piping</td>
<td>1.27</td>
<td>1063</td>
<td>1,350</td>
<td>957</td>
<td>1215</td>
<td>90</td>
</tr>
<tr>
<td>Large Bore Piping</td>
<td>1.02</td>
<td>9,600</td>
<td>9,792</td>
<td>4903</td>
<td>5001</td>
<td>51.1</td>
</tr>
<tr>
<td>All Piping (Control)</td>
<td>1.27</td>
<td></td>
<td>11,142</td>
<td>6,216</td>
<td></td>
<td>55.8</td>
</tr>
</tbody>
</table>

FORECASTING

WORKHOURS FORECAST AT ACTIVITY COMPLETION =

\[
\text{WORKHOURS TO DATE} \times \frac{\text{TOTAL ESTIMATED QUANTITY}}{\text{QUANTITY TO DATE}}
\]

= WORKHOURS TO DATE
% COMPLETE
### SUMMARY

- Productivity can be controlled
- Before Productivity can be improved it must be measured
- Productivity can be measured
- It can be measured separately from Cost Control Systems
- Productivity measurement can provide accurate reflection of job progress

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>UNITS OF MEASURE</th>
<th>WORK HOURS TO DATE</th>
<th>QUANTITY TO DATE</th>
<th>ESTIMATED QUANTITY</th>
<th>TOTAL FORECAST WORK HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIPING PIPING</td>
<td>LIN FT PIECE</td>
<td>1824</td>
<td>917</td>
<td>1066</td>
<td>2,121</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2350</td>
<td>1958</td>
<td>9790</td>
<td>11,750</td>
</tr>
<tr>
<td>STRUCT-STEEL</td>
<td>CAB LIN FT</td>
<td>782</td>
<td>517</td>
<td>638</td>
<td>965</td>
</tr>
<tr>
<td>LE</td>
<td></td>
<td>1060</td>
<td>14327</td>
<td>6819</td>
<td>5048</td>
</tr>
</tbody>
</table>

8/15/2017
SUMMARY

• Performance Factor is a measure of construction efficiency
• Performance factors can be used to forecast future productivity and project completion
• Earned Value can be used to Measure % complete of a workpackage consisting of a group of activities.

Single Activity Productivity or System Productivity ?

Symptom or Root Cause ?
Exercise – 2

Suppose you are constructing an 8-foot high x 138-foot reinforced concrete retaining wall using 2’ x 8’ modular panels. The partially completed status of the work is shown below. Using the following rules of credit, calculate the cumulative quantity of formwork installed in terms of SFCA (square feet of contact area).

<table>
<thead>
<tr>
<th>Subtask</th>
<th>Unit of Measure</th>
<th>Rule of Credit</th>
<th>Subtask qty</th>
<th>Total quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erect wall formwork</td>
<td>SFCA</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brace and plumb</td>
<td>SFCA</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strip and clean</td>
<td>SFCA</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total task</td>
<td>SFCA</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stripped Concrete placed Ready for placement Formwork erected

Need Today….Project Delivery!!

Are we organized to deliver projects ??
Are our contracting strategies appropriate ?
Lean Project Delivery Framework