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USES OF DRONE APPLICATIONS TO MONITOR PRODUCTIVITY

ABSTRACT-

Drones are Unmannered Aerial Vehicles (UAV) that are having different applications because of the amount of information that they can collect in a short period of time during flight inspections.

It is also, one of the technologies that are rapidly increasing its use in construction, agriculture, maintenance, building design, mining, solar, etc.

Drones are capable nowadays to help to do surveys, calculate volumes, monitor risks prior to and during construction, identify damages in assets, monitor weather, to increase the safety of personnel getting access where humans would have difficulties, improve overall security, monitor progress, etc.

As a project controller, the author wants to analyse if drones, as support of project control activities when monitoring progress, might help to monitor productivity factors.

What are those productivity factors that a drone can help to measure and facilitate project controller's activities?

This research is important to analyse how this new technology based on drone data can support project control activities to monitor root causes that might affect productivity.

Conclusions show that this new technology can monitor root causes that might affect productivity.

We also have determined that most of the root causes meet the following criteria: They are tangible (through people, equipment, materials) and areas that they occupy can be located when programming drone's path.

KEY WORDS- Unmanned Aerial Vehicles (UAV), Drones, Project Control, Monitoring Progress, Project Management, Monitoring and Control, Productivity, Time – Wasters, Resource Management.

INTRODUCTION-

New technologies are helping projects in different sectors to become more successful in designing, in executing and in monitoring the development, operation and maintenance of future assets.

According to Geniebelt[1], the top 10 construction technology trends in 2019 are:

1. Augmented reality
2. Construction software and data ecosystem
3. Building Information Modelling
4. Modular Construction
5. Self-healing concrete
6. Drones
7. Robotics
8. Cloud and mobile technology
9. Advanced uses for GPS
10. Wearable technology

Not only because of the economical grow that is predicted to have in the following years, but because they will help to be more efficient in using data, in saving time in construction, in improving design, in having a better control of the construction activities and other areas that would contribute to use resources efficiently, increase performance and the most important, to meet budgets and time for owners and contractors.

One of the technologies that are rapidly increasing its use in construction is the Drone.

Drones are Unmannered Aerial Vehicles (UAV) that are having different applications because of the amount of information that they can collect in a short period of time during flight inspections.

Levin, P.[2], mentions that drones can contribute as a support tool for construction and project controls.

For construction, Levin lists several potential uses of drones, as shown in the following table:

[1] GenieBelt. (2018, October 2). Top 10 construction technology trends for 2019. Retrieved from https://geniebelt.com/blog/top-10-construction-technology-trends-for-2019

[2] Levin, P. (2015). CSC.1851- Drones for Project Controls and Other Uses on Construction Projects. AACE International, Morgantown, WV

Contract document photos	Marketing and sales	Progress photos
Pre-bid site investigation	Pre-construction site review	Design review
Existing conditions verification	Claims prevention	Claims resolution
Quality control inspection	Safety inspection	Equipment inspection
Energy use planning	Energy audit	Project documentation
Constructability	Job planning	BIM model development
Production measurement	Job coordination	Access planning
Adjacent property monitoring	Surveys	Quantity measurement
Post-storm reconnaissance	Emergency response aid	Small parcel deliveries
Site security	Punch-list aid	Final inspection

Table 1 Potential Construction Support Activities for Drones[3]

Regarding project controls, the drone's support is summed up in two words – progress measurement and documentation of the information.

Drones are capable nowadays to help to do surveys, calculate volumes, monitor risks prior to and during construction, identify damages in assets, monitor weather, to increase the safety of personnel getting access where humans would have difficulties, improve overall security, monitor progress, etc.

As a project controller, the author wants to analyse if drones, as support of project control activities when monitoring progress, might help to monitor productivity factors.

Productivity is a key input when calculating estimates and scheduling. Besides, it is also important to monitor resources' performance in order to assess and collect data for future similar projects.

Resources in projects are categorized as follows:

- Labour
- Material
- Equipment

Optimized use of these resources will avoid poor performance and poor productivity. In addition, it can impact directly competitiveness and increase profitability in the organization.

Some productivity factors are craft skills, weather conditions, project size, new plant at an open raw field (green field), new plant next to existing operating plant with tie-ins (brownfield), additions within existing plant, revamping and tie-ins, craft availability, shift work durations, work space/height, location, field supervision, new/older equipment and tools, material availability, average construction services and support, measurements are not accurate, incomplete technical documentation, client interface during engineering, daily safety and permits, acceleration, defective engineering, engineering recycle and or rework, excessive overtime, learning curve, poor morale of craft labour, poor project management, out of sequence work, schedule compression, type of contract, etc.

[3] Levin, P. (2015). CSC.1851- Drones for Project Controls and Other Uses on Construction Projects. AACE International, Morgantown, WV

Productivity factors are an important input for managing contracts, managing databases, for planning and scheduling and managing cost estimating and budgeting processes. In addition, the information captured can help to be useful for forecasting.

This research is important to analyse how this new technology based on drone data can support project control activities to monitor root causes that might affect productivity.

METHODOLOGY-

Step 1

Productivity is a key input when calculating estimates and scheduling. Besides, it is also important to monitor resources' performance in order to assess and collect data for future similar projects.

In recent years, monitoring progress of project resources have been done by drones. Drones do visual inspections and have applications in different sectors and different phases of the life cycle of an asset.

We are afraid that in the near future, drones would replace project controllers or supervisors for monitoring work, but the author believes that drones will complement and they will facilitate monitoring productivity factors.

What are those productivity factors that a drone can help to measure and facilitate project controller's activities?

Step 2

Alternative Solutions

There are three types of drones in the market that can be used for construction. Main features to consider when purchasing a drone are:

- Fixed wing vs VTOL (vertical-take-off-and-landing) vs tethered VTOL
- The weight it can carry
- How long it can flight
- The distance it can be operated and how quickly it can move in any direction

The following figure describes better these features:

Figure 1 Type of Drones and Features[4]

The equipment that comes with drones is also important to analyse because drones are not compatible with all the equipment. Equipment choices are:

- Cameras for photos and video (with sensors)
- GPS sytems
- Thermal Sensors (for heat)

Drones are not able to analyse data by itself. It requires photogrammetry software to process collected data and finally based on the sector or the need to use other applications in order to analyze the information.

A drone produces imagery and videos. Drone's data is processed by a Photogrammetry software which produces at least the following information:

- Photos
- Videos
- Densified Point Clouds
- 3D Textured Mesh
- Level Of Details (LOD) Mesh
- Orthomosaic Maps
- Reflectance Maps
- Digital Terrain Models (DTMs)
- Digital Surface Models (DSMs)
- CAD Overlays

This information can be used depending on the application and what we want to monitor and analyse.

[4] Higgins, A. (2017, May 5). Beginner's Guide to Using Drones for Construction Management. Retrieved from https://connect.bim360.autodesk.com/drones-for-construction-management

Step 3

The data can be used in the following applications mentioned by Pix4D (2018):

- Connection of lines with equal elevation
- Measure distance and surfaces
- To calculate volumes
- Comparison of volumes (for DSMs)
- Digitization of 2D
- Digitization of 3D
- Visualization of 3D
- Google applications for visualization
- Indices of Vegetation- Visualization of Index and Edition of Colours
- Indices of Vegetation – Applications for Agriculture
- Classification of Point Clouds
- View in stereo
- Print in 3D
- Visualization of lines connected and edition
- View from Web and Share from Web
- View of Video animation
- Visualization and editing of objects digitized in 3D
- Field Inspections (Index Map)
- Adjustments of Bundles

The description of each application will not be part of the current research. If the reader wants more information he or she can visit: https://support.pix4d.com/hc/en-us/categories/360000059123-General, where there is a brief description of each topic.

Step 4

The following attributes will be considered for the selection criteria:

We want to identify which applications from the previous step can help to monitor the following root causes of productivity factors:

Productivity Factor	Root Causes
1. Location	
Weather features	Air humidity
	High/low temperatures
	Rain
	High winds
Elevation	
Access	Waiting for access or removal of lockouts;
Skills of local personnel	Craft Availability
	Absentees - work must be reorganized
	Limited availability of a critical skill that must be shared among crews (e.g., a competent person required)
Logistic support is permanent	Shortage or late supply of materials and tools
	Construction Equipment and Tools
	Materials and Lay-down Area
	Do not collect all the necessary materials the first time.
	Insufficient Support Equipment(e.g., crane)
	Deterioration of materials and equipment in storage;
	Materials and equipment listed in inventory are missing;
	Tools are wrong or defective;
Traffic into site	
Attitude of nearby communities	
Transportation network	Distance between construction sites and cities
Local economy	Location/Cultural Interface
2. Project and Contract Characteristics	
Size of Projects	Project scale
	Type of Plant / Facility
	Project Size - Construction
Schedule constraints	Construction method
	Inadequate planning
	Unrealistic scheduling
	Undefined scope forces constant reworking of schedule
	Work is started before being fully planned and without all resources needed;
Lack of Scope Definition	Errors of fabrication or specifications for installation of materials and equipment
	Individuals don't understand their roles or responsibilities—must always ask questions
	Changes are issued—both formal and constructive;
	Issuing instructions after work has started;
Complexity of design for construction	Complexity of the design
	Construction mistakes.

Vulnerability to hazards	Unexpected conditions require work reorganization;
Requirements to meet environmental Laws	
Elevation and deepness of work	Influence of working at height
Types of Contracts	Construction Services
	Contractual disputes;
Budget constraints	Delays in payments to suppliers
Meet Engineering Quality Expectations	Clarity of the drawings and project documents
	Engineering and Technical Interface
The degree of the bottleneck or restraint	High congestion
	Motion´s limitation in the job site
	Excessive distances between working job sites
	Waiting for other crews to get out of way;
Access to existing facilities	
Distance to other construction sites	
Rework	
Safety and Permissions	Permits (such as hot work permits) not available
	Daily renewal of permits
	Safety incidents
3. Human Factors	
Competent Management Personnel	
Competent Field Supervision	Insufficient supervision of subcontractors
	Lack or delay in supervision
	Improper coordination of subcontractors
	Waiting for an approval to do something
	Lack of information or waiting for instructions
	Over-inspections
Insufficient worker skills	Level of Skill and experience
	Craft Skills
	Conflicts with operating plant personnel on revampinging work;
Work rules	Clear and daily task assignment
	Unjustified working rules
	Outdated policies or procedures that must be interpreted to fit current needs;
Personal pride	Labour motivation / Worker´s integrity
Stability of employment	Delays in payments to workers
Overtime	Working overtime
	Work Shift Durations
	Performing work at night
Experience/point on learning curve	Coordination between crews
Worker attitudes	Ability to adapt to changes and new environments
Crew stability/key personnel turnover	Reallocation of labourers

	Labour conflicts and union activity opposition;
	Incentive policies
Owner/contractor relationships	Communication problems
	Client Interface
Value system	
Personalities	Temperament problems between key staff of the owner, engineer and contractor;
Number of breaks and duration	

Table 2 Root Causes that affect Productivity Factors[5]

[5] By the Author. See Annexe 1.

FINDINGS-

Step 5

The author has elaborated the table below where we can identify which of the applications have more use in monitoring root causes that affect productivity factors. The first table correspond to Location Productivity Factors. It is split into three tables.

	1. Location								
	Weather features				Elevation	Access	Skills of local personnel		
	Air humidity	High/low temperatures	Rain	High winds		Waiting for access or removal of lockouts;	Craft Availability	Absentees - work must be reorganized	Limited availability of a critical skill that must be shared among
Connection of lines with equal elevation									
Measure distance and surfaces									
To calculate volumes									
Comparison of volumes (for DSMs)									
Digitization of 2D						X			
Digitization of 3D						X			
Visualization of 3D						X			
Google applications for visualization						X			
Indices of Vegetation- Visualization of Index and Edition of Colours									
Indices of Vegetation – Applications for Agriculture									
Classification of Point Clouds									
View in stereo									
Print in 3D									
Visualization of lines connected and edition									
View from Web and Share from Web		X				X	X		
View of Video animation						X	X		
Visualization and editing of objects digitized in 3D									
Field Inspections (Index Map)									
Adjustments of Bundles									

Table 3 Matrix of Applications against Root Causes of Productivity for Location Productivity Factors[6]

[6] By the Author

	1. Location							
	Logistic support is permanent							
	Shortage or late supply of materials and tools	Construction Equipment and Tools	Materials and Lay-down Area	Do not collect all the necessary materials the first time.	Insufficient Support Equipment(e.g., crane)	Deterioration of materials and equipment in storage;	Materials and equipment listed in inventory are missing;	Tools are wrong or defective;
Connection of lines with equal elevation								
Measure distance and surfaces			X					
To calculate volumes								
Comparison of volumes (for DSMs)								
Digitization of 2D	X	X	X			X		
Digitization of 3D	X	X	X			X		
Visualization of 3D	X	X	X			X		
Google applications for visualization	X	X	X			X		
Indices of Vegetation- Visualization of Index and Edition of Colours								
Indices of Vegetation – Applications for Agriculture								
Classification of Point Clouds								
View in stereo								
Print in 3D								
Visualization of lines connected and edition								
View from Web and Share from Web	X	X	X			X	X	
View of Video animation	X	X	X			X		
Visualization and editing of objects digitized in 3D								
Field Inspections (Index Map)								
Adjustments of Bundles								

Table 4 Matrix of Applications against Root Causes of Productivity for Location Productivity Factors[7]

[7] By Author

	1. Location			
	Traffic into site	Attitude of nearby communities	Transportation network	Local economy
			Distance between construction sites and cities	Location/ Cultural Interface
Connection of lines with equal elevation				
Measure distance and surfaces			X	
To calculate volumes				
Comparison of volumes (for DSMs)				
Digitization of 2D				
Digitization of 3D				
Visualization of 3D				
Google applications for visualization				
Indices of Vegetation- Visualization of Index and Edition of Colours				
Indices of Vegetation – Applications for Agriculture				
Classification of Point Clouds				
View in stereo				
Print in 3D				
Visualization of lines connected and edition				
View from Web and Share from Web	X			
View of Video animation	X			
Visualization and editing of objects digitized in 3D				
Field Inspections (Index Map)				
Adjustments of Bundles				

Table 5 Matrix of Applications against Root Causes of Productivity for Location Productivity Factors[8]

[8] By Author

The second table corresponds to Project and Contract Characteristics: it is spilt into three tables

	2. Project and Contract Characteristics											
	Size of Projects			Schedule constraints					Lack of Scope Definition			
	Project scale	Type of Plant / Facility	Project Size - Construction	Construction method	Inadequate planning	Unrealistic scheduling	Undefined scope forces constant reworking of schedule	Work is started before being fully planned and without all resources needed;	Errors of fabrication or specifications for installation of materials and equipment	Individuals don't understand their roles or responsibilities—must always ask questions	Changes are issued—both formal and constructive;	Issuing instructions after work has started;
Connection of lines with equal elevation												
Measure distance and surfaces												
To calculate volumes												
Comparison of volumes (for DSMs)												
Digitization of 2D												
Digitization of 3D												
Visualization of 3D												
Google applications for visualization												
Indices of Vegetation- Visualization of Index and Edition of Colours												
Indices of Vegetation – Applications for Agriculture												
Classification of Point Clouds												
View in stereo												
Print in 3D												
Visualization of lines connected and edition												
View from Web and Share from Web												
View of Video animation									X			
Visualization and editing of objects digitized in 3D												
Field Inspections (Index Map)												
Adjustments of Bundles												

Table 6 Matrix of Applications against Root Causes of Productivity for Project and Contract Characteristics Productivity Factors[9]

[9] By the Author

	2. Project and Contract Characteristics									
	Complexity of design for construction		Vulnerability to hazards	Requirements to meet environmental Laws	Elevation and deepness of work	Types of Contracts		Budget constraints	Meet Engineering Quality Expectations	
	Complexity of the design	Construction mistakes.	Unexpected conditions require work reorganization;		Influence of working at height	Construction Services	Contractual disputes;	Delays in payments to suppliers	Clarity of the drawings and project documents	Engineering and Technical Interface
Connection of lines with equal elevation		X							X	X
Measure distance and surfaces		X			X				X	X
To calculate volumes		X								
Comparison of volumes (for DSMs)		X							X	
Digitization of 2D		X							X	X
Digitization of 3D		X			X					X
Visualization of 3D		X			X					X
Google applications for visualization		X			X					X
Indices of Vegetation- Visualization of Index and Edition of Colours										
Indices of Vegetation – Applications for Agriculture										
Classification of Point Clouds										
View in stereo										
Print in 3D										X
Visualization of lines connected and edition									X	X
View from Web and Share from Web		X							X	X
View of Video animation		X							X	X
Visualization and editing of objects digitized in 3D					X				X	X
Field Inspections (Index Map)		X								
Adjustments of Bundles										

Table 7 Matrix of Applications against Root Causes of Productivity for Project and Contract Characteristics Productivity Factors[10]

[10] By Author

	2. Project and Contract Characteristics									
	The degree of the bottleneck or restraint				Access to existing facilities	Distance to other construction sites	Rework	Safety and Permissions		
	High congestion	Motion´s limitation in the job site	Excessive distances between working job sites	Waiting for other crews to get out of way;				Permits (such as hot work permits) not available	Daily renewal of permits	Safety incidents
Connection of lines with equal elevation			X							
Measure distance and surfaces			X							
To calculate volumes										
Comparison of volumes (for DSMs)										
Digitization of 2D			X							
Digitization of 3D			X							
Visualization of 3D	X	X	X							
Google applications for visualization	X	X	X							
Indices of Vegetation- Visualization of Index and Edition of Colours										
Indices of Vegetation – Applications for Agriculture										
Classification of Point Clouds										
View in stereo										
Print in 3D										
Visualization of lines connected and edition			X							
View from Web and Share from Web	X	X	X							
View of Video animation	X	X	X							
Visualization and editing of objects digitized in 3D										
Field Inspections (Index Map)	X	X								
Adjustments of Bundles										

Table 8 Matrix of Applications against Root Causes of Productivity for Project and Contract Characteristics Productivity Factors[11]

[11] By Author

And the last table is for Human Factors: It is split into three tables.

	3. Human Factors												
	Competent Management Personnel	Competent Field Supervision						Insufficient worker skills			Work rules		
		Insufficient supervision of subcontractors	Lack or delay in supervision	Improper coordination of subcontractors	Waiting for an approval to do something	Lack of information or waiting for instructions	Over-inspections	Level of Skill and experience	Craft Skills	Conflicts with operating plant personnel on	Clear and daily task assignment	Unjustified working rules	Outdated policies or procedures that must be
Connection of lines with equal elevation													
Measure distance and surfaces													
To calculate volumes													
Comparison of volumes (for DSMs)													
Digitization of 2D													
Digitization of 3D													
Visualization of 3D													
Google applications for visualization		X											
Indices of Vegetation- Visualization of Index and Edition of Colours													
Indices of Vegetation – Applications for Agriculture													
Classification of Point Clouds													
View in stereo													
Print in 3D													
Visualization of lines connected and edition													
View from Web and Share from Web		X						X	X	X			
View of Video animation		X						X	X	X			
Visualization and editing of objects digitized in 3D													
Field Inspections (Index Map)													
Adjustments of Bundles													

Table 9 Application against Root Causes of Human Productivity Factors[12]

[12] By Author

	3. Human Factors						
	Personal pride	Stability of employment	Overtime			Experience/point on learning curve	Worker attitudes
	Labour motivation / Worker´s integrity	Delays in payments to workers	Working overtime	Work Shift Durations	Performing work at night	Coordination between crews	Ability to adapt to changes and new environments
Connection of lines with equal elevation							
Measure distance and surfaces							
To calculate volumes							
Comparison of volumes (for DSMs)							
Digitization of 2D							
Digitization of 3D							
Visualization of 3D							
Google applications for visualization							
Indices of Vegetation- Visualization of Index and Edition of Colours							
Indices of Vegetation – Applications for Agriculture							
Classification of Point Clouds							
View in stereo							
Print in 3D							
Visualization of lines connected and edition							
View from Web and Share from Web			X	X	X		
View of Video animation							
Visualization and editing of objects digitized in 3D							
Field Inspections (Index Map)							
Adjustments of Bundles							

Table 10 Application against Root Causes of Human Productivity Factors[13]

[13] By Author

	3. Human Factors							
	Crew stability/key personnel turnover			Owner/contractor relationships		Value system	Personalities	Number of breaks and duration
	Reallocation of labourers	Labour conflicts and union activity opposition;	Incentive policies	Communication problems	Client Interface		Temperament problems between key staff of the owner, engineer and contractor;	
Connection of lines with equal elevation								
Measure distance and surfaces								
To calculate volumes								
Comparison of volumes (for DSMs)								
Digitization of 2D								
Digitization of 3D								
Visualization of 3D								
Google applications for visualization								
Indices of Vegetation- Visualization of Index and Edition of Colours								
Indices of Vegetation – Applications for Agriculture								
Classification of Point Clouds								
View in stereo								
Print in 3D								
Visualization of lines connected and edition								
View from Web and Share from Web								
View of Video animation								
Visualization and editing of objects digitized in 3D								
Field Inspections (Index Map)								
Adjustments of Bundles								

Table 11 Application against Root Causes of Human Productivity Factors[14]

[14] By Author

Step 6

After the previous analysis, we can determine that most of the imagery and videos produced by the applications from drone data, can help to monitor root causes that affect productivity factors.

The applications identified are:

- Connection of lines with equal elevation
- Measure distance and surfaces
- To calculate volumes
- Comparison of volumes (for DSMs)
- Digitization of 2D
- Digitization of 3D
- Visualization of 3D
- Google applications for visualization
- Indices of Vegetation- Visualization of Index and Edition of Colours
- Indices of Vegetation – Applications for Agriculture
- Classification of Point Clouds
- View in stereo
- Print in 3D
- Visualization of lines connected and edition
- View from Web and Share from Web
- View of Video animation
- Visualization and editing of objects digitized in 3D
- Field Inspections (Index Map)
- Adjustments of Bundles

We also have determined that most of the root causes are tangible and occupy space so they can be located when programming drone's path.

Step 7

How can project controllers get confidence that drone applications are really helping them to keep good performance of project or enterprise resources?

When productivity factors are very close to used when estimating or budgeting.

When conducting a root cause analysis of delays or cost overruns, we can see that Pareto charts or Fishbone diagrams, these factors are not part of the top list. But the list requires new action plans for new factors.

In addition, when implementing action plans, there is a recovery in progress if the project was delayed or actual costs decreases.

CONCLUSIONS-

We have determined that this new technology based on drone data can support project control activities to monitor root causes that might affect productivity.

The applications identified are 14 out 19 produced by the provider chosen:

- Connection of lines with equal elevation
- Measure distance and surfaces
- To calculate volumes
- Comparison of volumes (for DSMs)
- Digitization of 2D
- Digitization of 3D
- Visualization of 3D
- Google applications for visualization
- Indices of Vegetation- Visualization of Index and Edition of Colours
- Indices of Vegetation – Applications for Agriculture
- Classification of Point Clouds
- View in stereo
- Print in 3D
- Visualization of lines connected and edition
- View from Web and Share from Web
- View of Video animation
- Visualization and editing of objects digitized in 3D
- Field Inspections (Index Map)
- Adjustments of Bundles

We also have determined that most of the root causes meet the following criteria: They are tangible (through people, equipment, materials) and areas that they occupy can be located when programming drone's path.

Besides, some advantages of these applications are that reduces time to calculations, information can be shared in real time and can be seen anywhere in the new platforms specialised of drone information.

FOLLOW ON RESEARCH-

From the previous analysis, it would be interesting to determine if these applications could serve as inputs for other Project Management Software in order to calculate progress in a traditional way or only a few methods to calculate progress are more suitable to these applications.

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List of Tables

APPENDICES-

Appendix 1 – Root Causes that Affect Productivity Factors.

Resources in projects are categorized as follows:

- Labour
- Material
- Equipment

Optimized use of these resources will avoid poor performance and poor productivity. In addition, it can impact directly competitiveness and increase profitability in the organization.

Skills and Knowledge (S&K) of Cost Engineering (6th edition) defines that to evaluate an organization we can use a Success Index (SI) which differs from Productivity Index (PI). Success Index is defined as:

Success Index = (net profit) / (total cost)

Success Index = (value of services rendered) / (essential cost + cost of waste)

Cost of waste is divided into the following categories:

- Inefficiencies when designing and operating
- Inefficiencies related to individuals
- Non-contributing activities from individuals
- Materials, supplies, and services that are misused, overused, lost
- Abuse, misuse or loss of equipment
- Functions that no longer add value to the output of the organization

For the current analysis S&K identified the following list of time wasters in a construction field site:

1. Undefined scope forces constant reworking of schedule;
2. Contractual disputes;
3. Labour conflicts and union activity opposition;
4. Unjustified working rules;
5. Temperament problems between key staff of the owner, engineer and contractor;
6. Late delivery of materials or installed equipment;
7. Errors of fabrication or specifications for installation of materials and equipment;
8. Deterioration of materials and equipment in storage;
9. Materials and equipment listed in inventory are missing;
10. Do not collect all the necessary materials the first time.;
11. Excessive distances between working job sites;
12. Tools are wrong or defective;
13. Insufficient Support Equipment(e.g., crane);
14. Waiting for an approval to do something;
15. Lack of information or waiting for instructions;

16. Issuing instructions after work has started;
17. Waiting for other crews to get out of way;
18. Individuals don't understand their roles or responsibilities—must always ask questions;
19. Limited availability of a critical skill that must be shared among crews (e.g., competent person required by OSHA for certain operations);
20. Late starts/early quits;
21. Absentees—work must be reorganized;
22. Discipline problems;
23. Permits (such as hot work permits) not available;
24. Daily renewal of permits;
25. Conflicts with operating plant personnel on revamping work;
26. Operating personnel, having not been consulted during development of the project, make changes on the fly;
27. Changes are issued—both formal and constructive;
28. Unexpected conditions require work reorganization;
29. Waiting for access or removal of lockouts;
30. Over-inspections;
31. Outdated policies or procedures that must be interpreted to fit current needs;
32. Work is started before being fully planned and without all resources needed;
33. Safety incidents;
34. Construction mistakes.

In addition, there are other factors that impact productivity as follows:

1. Location
    a. Weather features
    b. Elevation
    c. Access to site
    d. Skills of local personnel
    e. Logistic support is permanent
    f. Traffic into site
    g. Attitude of nearby communities
    h. Transportation network
    i. Local economy
2. Project and Contract Characteristics
    a. Size of Projects
    b. Schedule constraints
    c. Lack of Scope Definition
    d. Complexity of design for construction

e. Vulnerability to hazards
f. Requirements to meet environmental Laws
g. Elevation and deepness of work
h. Types of Contracts
i. Budget constraints
j. Meet Engineering Quality Expectations
k. The degree of the bottleneck or restraint
l. Access to existing facilities
m. Distance to other construction sites

3. Human Factors

a. Competent Management Personnel
b. Competent Field Supervision
c. Insufficient worker skills
d. Work rules
e. Personal pride
f. Stability of employment
g. Overtime
h. Experience/point on learning curve
i. Worker attitudes
j. Crew stability/key personnel turnover
k. Owner/contractor relationships
l. Value system
m. Personalities

We can also list more labour productivity factors mentioned by the following authors:

G. Robles, A. Stifi, José L. Ponz-Tienda, S. Gentes

Code	Factor	Category
F1	Construction method	Project category
F2	Complexity of the design	
F3	Clarity of the drawings and project documents	
F4	Project scale	
F5	Level of Skill and experience	Human category
F6	Ability to adapt to changes and new environments	
F7	Labour motivation	
F8	Working overtime	
F9	Number of breaks and duration	
F10	Worker´s integrity	
F11	Incentive policies	Management or organizational category
F12	Clear and daily task assignment	
F13	Insufficient supervision of subcontractors	
F14	Improper coordination of subcontractors	

F15	Inadequate planning	
F16	High congestion	
F17	Delays in payments to workers	
F18	Delays in payments to suppliers	
F19	Unrealistic scheduling	
F20	Communication problems	
F21	Reallocation of labourers	
F22	Coordination between crews	
F23	Lack or delay in supervision	
F24	Rework	
F25	Shortage or late supply of materials and tools	Materials and tools category
F26	Unsuitability of materials storage location category	
F27	Tools or equipment shortages	
F28	Performing work at night Environmental	Environmental category
F29	Influence of working at height category	
F30	Motion´s limitation in the job site	
F31	Air humidity	
F32	High/low temperatures	
F33	Rain	
F34	High winds	
F35	Distance between construction sites and cities	

Table 12 Labour Productivity Factors[15]

And according to Mahendra Pal Bathia[16], we can assess the following categories of Labour Productivity Factors:

1. Direct Site Specific
    a. Type of Plant / Facility
        i. New Plant at an Open Raw Field (Green Field)
        ii. New Plant next to Existing Operating Plant with Tie-ins (Brown Field)
        iii. Additions within Existing Plant, Revamping and Tie-ins
        iv. Revamping and Tie-Ins only
    b. Craft Skills
        i. Highly Skilled and Experienced

[15] 28. G. Robles, A. Stifi, José L. Ponz-Tienda, S. Gentes. (2014). Labour Productivity in the Construction Industry - Factors Influencing the Spanish Construction Labour Productivity. World Academy of Science, Engineering and Technology International Journal of Civil and Environmental Engineering Vol:8, No:10. International Scholarly and Scientific Research & Innovation 8(10) 2014.

[16] 27. Pal Bhatia, M. (2012). EST.1146 – Elements Affecting Productivity and its Relationships. AACE International, Morgantown, WV

ii. Above Average

iii. Average

iv. Fair Poor

c. Craft Availability

i. Soft Business Climate – Selective

ii. Above Average

iii. Average

iv. Fair

v. Poor

d. Weather and Wind

e. Shift Work

i. One Shift

ii. Two Shifts

iii. Three Shifts

f. Work Shift Durations

g. Work Space/Height

h. Location/Cultural Interface

i. Near Major Centre / No Cultural Interface

ii. Remote with Camp / No Cultural Interface

iii. Remote with Camp / Average Cultural Interface

iv. Remote with Camp / High Cultural Interface

v. Extremely Remote with Camp and Restrictive Access / High Cultural Interface

2. Indirect Site Specific

a. Field Supervision

i. Experienced and Proactive Staff with Above Average Planning

ii. Skilled Supervision with Average Planning and Changes

iii. Average Skilled Supervision with No Planning

iv. Poorly Skilled Supervision with No Planning

b. Construction Equipment and Tools

i. New and Well Maintained

ii. New but Poorly Managed and Maintained

iii. Older Equipment and Well Maintained

iv. Older Equipment and Poorly Managed and Maintained

c. Materials and Lay-down Area

i. Immediate Availability with no Field Work and nearby Lay-down Location

ii. Late Availability with some Field Re-work with Nearby Lay-down Location

iii. Late Availability and extensive Re-work and Distant Lay-down Area

d. Construction Services

i. Well Managed Services and Support

ii. Averaged Managed Services and Support

iii. Poorly Managed Services and Support

e. Construction Services

i. Well Managed Services and Support

ii. Averaged Managed Services and Support

iii. Poorly Managed Services and Support

f. Project Size - Construction

i. Less Than 250,000 Hours

ii. From 250,000 Hours to 1.0 Million Hours

iii. From 1.0 Million Hours to 2.5 Million Hours

iv. From 2.5 Million Hours to 4.5 Million Hours

v. 4.5 Million Hours and Above

3. Engineering and Technical Interface

i. Completed and well Documented Technical Documentation

ii. Completed Technical Documents with few Changes

iii. Incomplete Technical Documents

iv. Incomplete Technical Documents at Early Stage

4. Client Interface

i. Clear and Timely Decision towards completion of technical documents

ii. Unclear Interface with late decisions

iii. Unclear and Late Decisions with Changes

5. Safety and Permissions

i. No permits requirements Generally a Green Field Construction – General Safety Orientation

ii. Blanket Work Permits – Periodic Safety Meetings.

iii. Daily Permits – Daily Safety Meetings.

iv. Daily Permitting with restrictive Access – Extensive Safety Training / Meetings

Taking as a reference the categories from S&K, we will identify what subcategories include other time wasters or other factors mentioned by other authors. We want to facilitate the work of project controllers and summarize the list that can be monitored by drones.

Using Fishbone Diagram a first approach will give the following results:

The fishbone diagram for Project and Contract Characteristics will give the following diagram:

Figure 2 Fishbone Diagram of Project and Contract Characteristics[17]

[17] By Author

The fishbone diagram for Location will give the following figure:

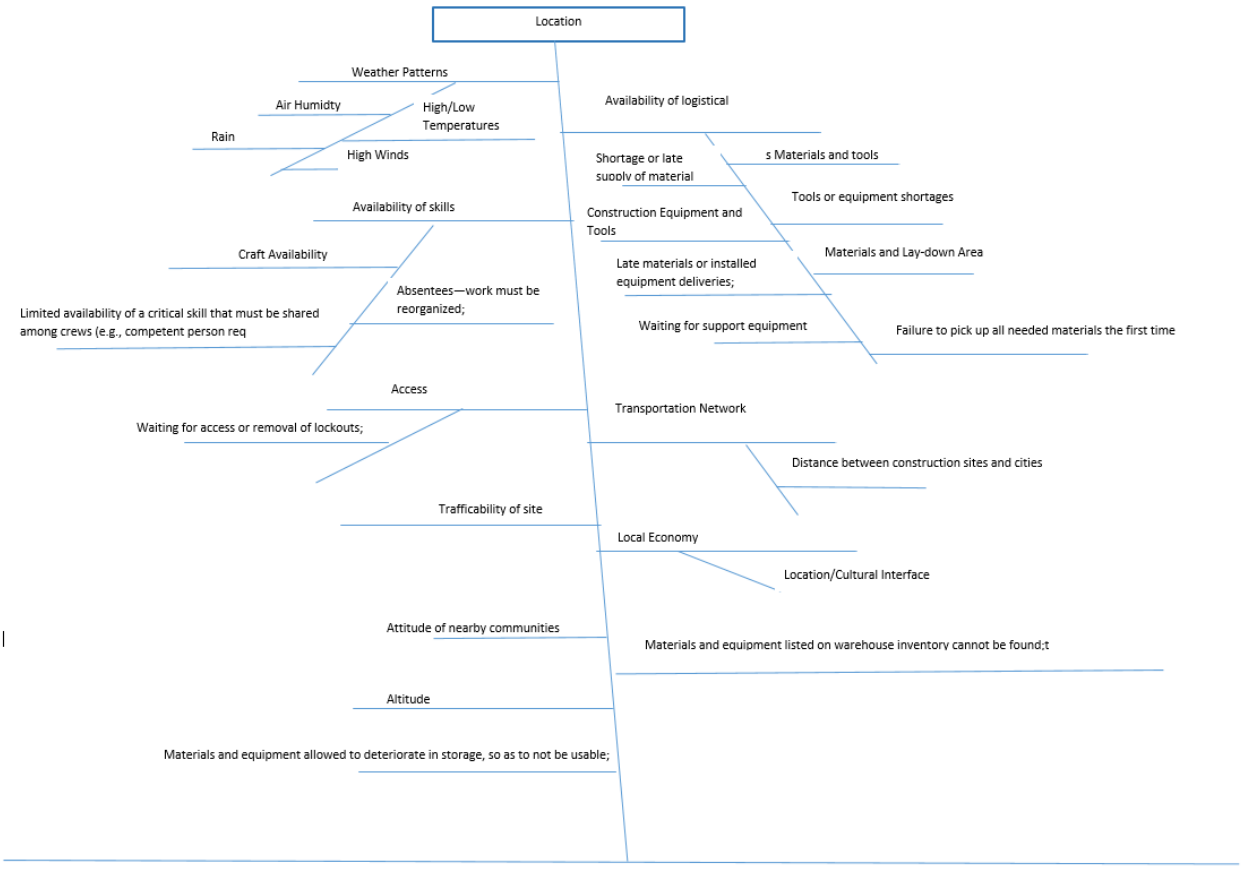

Figure 3 Fishbone Diagram of Location Productivity Factors[18]

[18] By Author

And the last Diagram for Human Factors is as follows:

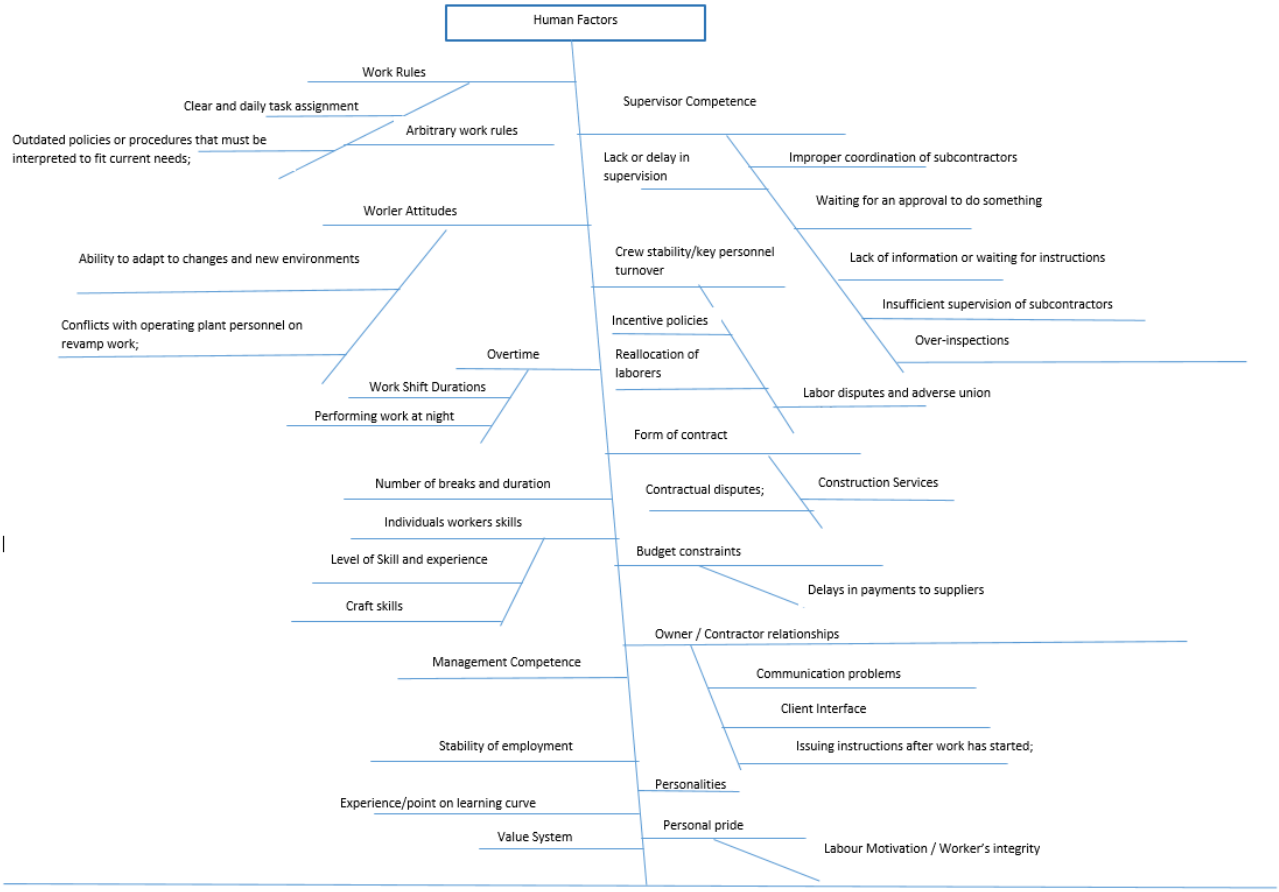

Figure 4 Fishbone Diagram of Human Factors Productivity Factors[19]

[19] By Author

A summarized table of Root Causes for Analysis is shown in the following table:

1. Location	
Weather features	Air humidity
	High/low temperatures
	Rain
	High winds
Elevation	
Access	Waiting for access or removal of lockouts;
Skills of local personnel	Craft Availability
	Absentees - work must be reorganized
	Limited availability of a critical skill that must be shared among crews (e.g., a competent person required)
Logistic support is permanent	Shortage or late supply of materials and tools
	Construction Equipment and Tools
	Materials and Lay-down Area
	Do not collect all the necessary materials the first time.
	Insufficient Support Equipment(e.g., crane)
	Deterioration of materials and equipment in storage;
	Materials and equipment listed in inventory are missing;
	Tools are wrong or defective;
Traffic into site	
Attitude of nearby communities	
Transportation network	Distance between construction sites and cities
Local economy	Location/Cultural Interface
2. Project and Contract Characteristics	
Size of Projects	Project scale
	Type of Plant / Facility
	Project Size - Construction
Schedule constraints	Construction method
	Inadequate planning
	Unrealistic scheduling
	Undefined scope forces constant reworking of schedule
	Work is started before being fully planned and without all resources needed;
Lack of Scope Definition	Errors of fabrication or specifications for installation of materials and equipment
	Individuals don't understand their roles or responsibilities—must always ask questions
	Changes are issued—both formal and constructive;
	Issuing instructions after work has started;

Complexity of design for construction	Complexity of the design
	Construction mistakes.
Vulnerability to hazards	Unexpected conditions require work reorganization;
Requirements to meet environmental Laws	
Elevation and deepness of work	Influence of working at height
Types of Contracts	Construction Services
	Contractual disputes;
Budget constraints	Delays in payments to suppliers
Meet Engineering Quality Expectations	Clarity of the drawings and project documents
	Engineering and Technical Interface
The degree of the bottleneck or restraint	High congestion
	Motion´s limitation in the job site
	Excessive distances between working job sites
	Waiting for other crews to get out of way;
Access to existing facilities	
Distance to other construction sites	
Rework	
Safety and Permissions	Permits (such as hot work permits) not available
	Daily renewal of permits
	Safety incidents
3. Human Factors	
Competent Management Personnel	
Competent Field Supervision	Insufficient supervision of subcontractors
	Lack or delay in supervision
	Improper coordination of subcontractors
	Waiting for an approval to do something
	Lack of information or waiting for instructions
	Over-inspections
Insufficient worker skills	Level of Skill and experience
	Craft Skills
	Conflicts with operating plant personnel on revamping work;
Work rules	Clear and daily task assignment
	Unjustified working rules
	Outdated policies or procedures that must be interpreted to fit current needs;
Personal pride	Labour motivation / Worker´s integrity
Stability of employment	Delays in payments to workers
Overtime	Working overtime

	Work Shift Durations
	Performing work at night
Experience/point on learning curve	Coordination between crews
Worker attitudes	Ability to adapt to changes and new environments
Crew stability/key personnel turnover	Reallocation of labourers
	Labour conflicts and union activity opposition;
	Incentive policies
Owner/contractor relationships	Communication problems
	Client Interface
Value system	
Personalities	Temperament problems between key staff of the owner, engineer and contractor;
Number of breaks and duration	