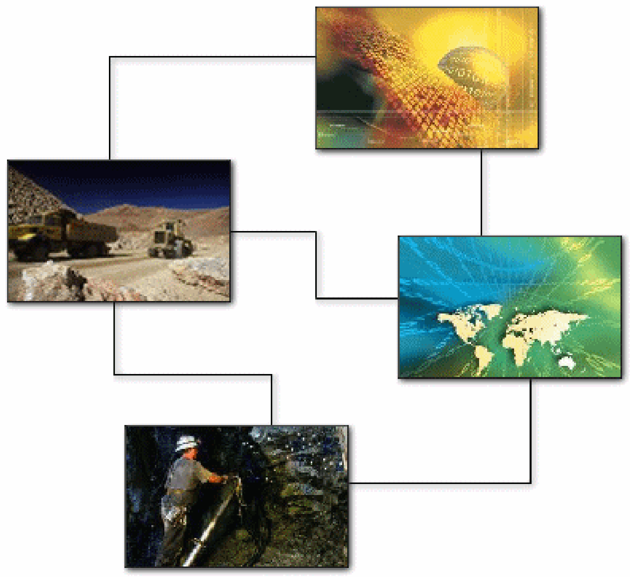
Loading and haulage in quarries: criteria for the selection of excavator - dumper system

PROCEEDINGS OF THE FOURTEENTH INTERNATIONAL SYMPOSIUM ON MINE PLANNING AND EQUIPMENT SELECTION (MPES 2005) AND THE FIFTH INTERNATIONAL CONFERENCE ON COMPUTER APPLICATIONS IN THE MINERALS INDUSTRIES (CAMI 2005)



MINE PLANNING AND EQUIPMENT SELECTION AND COMPUTER APPLICATIONS IN THE MINERALS INDUSTRIES

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Foreword

Raj K. Singhal

The basic aim of this conference is to contribute to the development of high-tech methods and technologies for the various segments of the mining and processing industries. A wide range of high quality papers from North and South America, Europe, Australia, Africa and Asia have been attracted. Major topics to be covered at MPES 2005 and CAMI 2005 are: Coal Mining Technologies: Processing Equipment and Quality Control; Open Pit Mine Planning, Design, and Productivity Gains; Underground Mine Planning and Design; Drilling, Blasting and Excavation Engineering; Mining Equipment Selection, Automation and Information Technology; Mine Maintenance and Production Management; e-Maintenance, e-Diagnostics, and Prognostics; Road Headers, Tunneling and Other Excavation Equipment; Case Histories From Coal Mining, Industrial Minerals and Metalliferous Mining; Cost Effective Methods of Mine Reclamation, Mine Closure and Waste Disposal; Rock Mechanics and Geotechnical Applications; Advances in Mine Design, Mine Optimization and Reclamation Planning Technologies; Mine Equipment: Design, Selection, and Real-Time Health and Performance Monitoring; Mine and Machine Automation; GIS, GPS, Telecommunications, Artificial Intelligence, and Internet Application; Rock Mechanics and Geotechnical Applications: Underground and Surface Mine Stability, Groundwater, Tailings and Waste Disposal; Computer Simulation; Real-Time Mine Management Systems; and Computer Applications in Mining Education.

MPES 2005 and CAMI 2005 are supported by a number of organizations. To be noted are: Department of Mining, Metallurgical and Materials Engineering, Universite Laval; Department of Mining and Mineral Process Engineering, University of British Columbia; Department of Mining, Metals and Materials, McGill University; Department of Energy and Geo-Environmental Engineering, The Pennsylvania State University; Laurentian University; Western Australian School of Mines, Curtin University of Technology, Australia; Department of Earth Resources and Mining Engineering, Kyushu University, Japan; Department of Civil and Environmental Engineering, University of Alberta; University of Alaska, Fairbanks; Henry Krumb School of Mines, Columbia University; Department of Earth Sciences, Simon Fraser University; International Journal of Surface Mining, Reclamation and Environment; Faculty of Geoengineering, Mining and Geology, Wroclaw University of Technology; Atilim University, Ankara, Turkey; Rock Engineering, Helsinki University of Technology, Finland; Department of Mining and Nuclear Engineering, University of Missouri-Rolla; The National Technical University of Athens, Greece (NTUA);; Dipartimento di Geoingegneria e Tecnologie Ambientali, Universita degli Studi di Cagliari, Italy; National Mining University of Ukraine, Dnipropetrovsk; CENTEK-International Training and Development Centre, Lulea University, Sweden; Faculty of Mining and Geology, VSB - Technical University, Ostrava, Czech Republic; and Hokkaido University, Mineral Resources Engineering Department, Japan.

The organization and success of such a symposium is due mainly to the tireless efforts of many individuals, authors included. All members of the Organizing Committee and conference chairpersons have contributed greatly. The support of our plenary session and invited speakers and co-chairs is gratefully acknowledged. My greatest appreciation goes to my daughter Dr. Meena Singhal who has worked tirelessly to ensure that proceedings appear on time and who has single-handedly developed the technical program. In addition, particular recognition is accorded to our sponsors, without whose support this conference might not have taken place, Margaret-Anne Stroh for managing administrative functions for CAMI/MPES, Merlene Sparks from Elk Valley Coal Corporation who compiled this CD and Walid Sabbagh of The Reading Matrix Inc. for technical support on the MPES and CAMI website.

This conference is designed to provide a forum for the presentation, discussion and debate of state-of-the-art and emerging technologies in the field of mining and computer applications in the minerals industries. Authors from over 15 countries with backgrounds in computer sciences, mining engineering, research, technology and management representing government, industry and academia concerned with mining and mineral production have contributed to these proceedings. The contents of this volume of proceedings will be of interest to engineers, scientists, consultants and government personnel who are responsible for dealing with the development and application of innovative technologies to the minerals industries. Papers on this CD are available in PDF format and are saved under the authors' last names (Adobe Acrobat is also provided).

LIST OF ARTICLES ON CD PROCEEDINGS

Loading and haulage in quarries: criteria for the selection of excavator-dumper system

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The optimisation of loading and haulage is one of the most important issues for the yield of quarrying activities. Many external factors may affect loading and haulage system selection: amongst them a very important role is played by local topography, stability conditions, size of the excavated material and capacity of the crusher. Of course, loading and haulage equipments affect one another and should be matched in order to get an efficient system, considering both production and economical aspects; selection criteria should be mainly based on:

- optimisation of loading system (sometimes working as excavation equipment too);
- optimisation of haulage system (in terms of both single equipment and fleet);
- optimisation of maintenance programs and organisation (in terms of availability of the system).

In particular, the paper deals with the hydraulic excavator – dumper (or truck) system, focusing on the relations between the technical characteristics of the equipments. Many loading and haulage operations have been analysed in different Italian open cast mines and quarries, in order to identify the best working relations and to derive a simple procedure for a proper selection.

Keywords: optimisation of mining operations; loading and haulage; excavators; dumpers

1. Foreword

The selection of the loading and haulage system is strongly affected by the global economy of the extraction unit, and should be based on a series of analysis bearing on, among others, the following subjects:

- optimisation of the loading machine, which can be used either to excavate directly from the face, or to muck blasted material;
- optimisation of the haulage stage, concerning the features of the individual machines and the composition of the fleet;
- optimisation of the organisation-maintenance choices, aimed to increase the availability of the system.

Loading and haulage are interconnected with the other steps of the production process, hence the selection of the best suited equipment is conditioned by a number of external factors. First, the morphological and topographic features of the site can impose absolute limits to the size of the machinery, independent from economy and production considerations. The same applies to the limits posed by the stability of the benches and of the face (Cvetkovic *et al*. 1999). Moreover, when the run of mine has to be subjected to primary crushing, the size of the bucket should be smaller than the maximum block size accepted by the crusher, to avoid the need of secondary blasting or mechanical breakage at the crushing plant feeding point.

Within the general limits posed by the above quoted restrictions, the paper, on the basis of a number of field surveys and literature data, tries to define optimal ratios between the most significant technical features of the loading and haulage machines in selected production sites.

2. Data acquisition

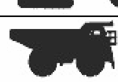
In the quarries analysed hydraulic shovels (front and backhoe) are used for loading and excavation, and dumper trucks for haulage.

Five sites, in Piemonte region (NW Italy), have been retained as "sample sites", and several "standard" loading and haulage operations have been monitored. Data were recorded in purposely prepared forms, to be treated with data processing programs. The following have been carefully determined:

- the mean volume loaded in a cycle by the excavation bucket, with an approximate evaluation of the size distribution of the material;
- the actual bucket filling, rotation, unloading, bucket return times and displacement of the shovel;
- the number of dump trucks engaged at any time in the operation;
- the mean volume actually loaded on the dump truck;
- the mean waiting time of the dump trucks, when more than one is used.

The information on the technical features of the machines has been obtained from manufacturers technical literature: bucket capacity; installed power of the shovel; ideal cycle time; dumper capacity; dumper installed power. The ranges of the most important features of the machines engaged in the sample sites are shown in table 1. Figure 1 shows the ranges of the characteristic ratios (power/capacity and power/ weight) of the machinery involved: it can be seen that the ranges of the machines employed in the sample sites are well within the general range.

Table 1. Ranges of the most important features of the machines engaged in the sample sites.

	Equipment	**Power kW**	**Weight t**	**Capacity m^3**
	Hydraulic excavator	80 - 230	19 - 50	1 - 3
	Front shovel excavator	306 - 728	75 - 200	4.5 - 9
	Dump truck	166 - 447	20 - 38	10 - 34

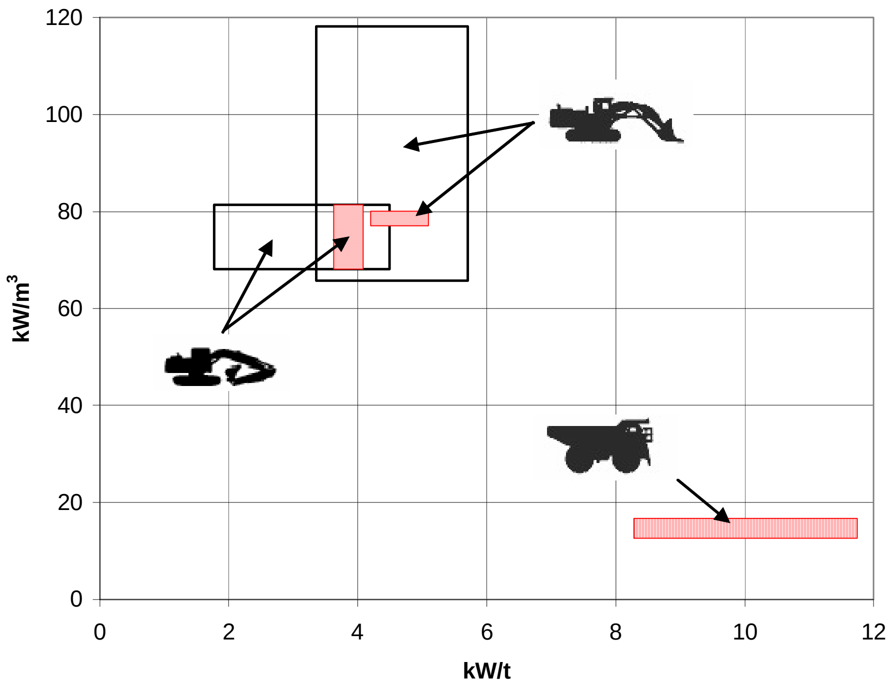


Figure 1. Ranges of the power/capacity and power/weight of the machines engaged: contoured area refers to the whole family of machines, coloured area to the sample sites machinery.

We can conclude that the sample sites are quite typical, as far as the fleet engaged is concerned.

3. Analysis of the data collected

Field collected data and information on machinery have been used to define generalizable correlations (assuming that the sample sites are a representative sample of the whole population of crushed stone quarries in our district), linking the technical features of the machinery to the production obtained.

3.1. Bucket capacity/dumper truck capacity correlation

The observed data are plotted in figure 2, showing a correlation coefficient quite high (0,78).

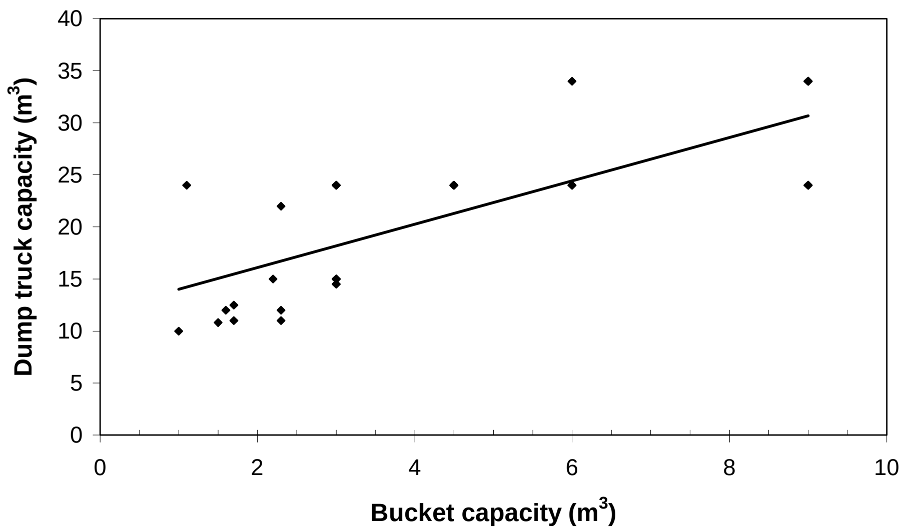


Figure 2. Correlation linking the bucket capacity to the truck capacity, in the sample sites.

The ratio truck capacity/bucket capacity varies in the 2.6 to 10 range (excluding one anomalous case), which qualitatively agrees with literature data (for example Rzhevsky, 1987, indicates a 4.7-10 range, for a comparable range of bucket capacities).

The average number of buckets required to fill a truck has been calculated: the mean value is 5.5, in agreement with literature data.

The degree of utilisation of the loading capacity (K) can be calculated as:

$$K = \frac{N_b \cdot V_E \cdot K_{BF} \cdot K_{RC}}{V_D} \qquad (1)$$

where:

N_b = number of buckets to fill the truck

V_E = bucket capacity (m^3)

K_{BF} = bucket filling coefficient (0.85-1.05)

K_{RC} = broken rock compaction coefficient (0.87-0.94)

V_D = truck capacity (m^3)

Calculated values for K (from all the data collected in the sample sites) are 0.8-0.9, slightly lower than optimal values quoted in literature (1-1.07).

The productivity of the whole shovel-truck system, hence bucket/truck capacity ratio, depends on the mutual position of the two machines, say on the availability of space and on the geometrical features of the site, that can make possible one side or both sides loading, as shown in figure 3.

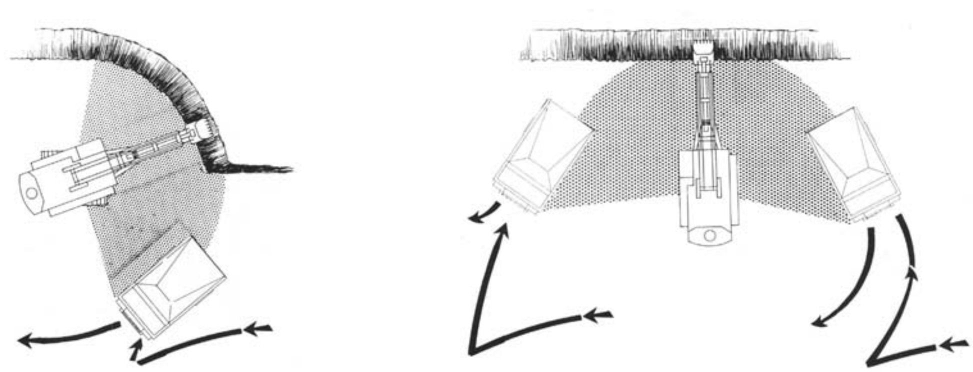


Figure 3. Schemes of one side (left) and both sides (right) loading of the trucks (Martin *et al.* 1982).

When applicable, both sides loading is preferred, making possible continuous loading, avoiding the shovel idle time due to the dump truck manoeuvre to get to the loading position.

If the haulage distance does not introduce further idle times, the relationship ideally linking the bucket capacity to the truck capacity and to the hourly production is:

$$V_E = \frac{V_D \cdot t_C}{(\frac{3600 \cdot V_D}{Q} - t_{wD}) \cdot K_{BF}} \quad (2)$$

where:

V_E = bucket capacity (m^3)

V_D = truck capacity (m^3)

t_C = shovel cycle time (s)

Q = hourly production (m^3/h)

t_{wD} = waiting time due to truck positioning

K_{BF} = bucket filling coefficient

Field data from the sample sites agree with equation (2), to within 10%.

By assuming the average value of 30 s, for average dump truck wait and shovel cycle time (from the measured data at the sample sites), the correlation linking bucket capacity, truck capacity and hourly production is represented by the nomogram of figure 4, which can be confidently used for practical purposes (in the case t_{wD} = 0, the production depends only on bucket capacity).

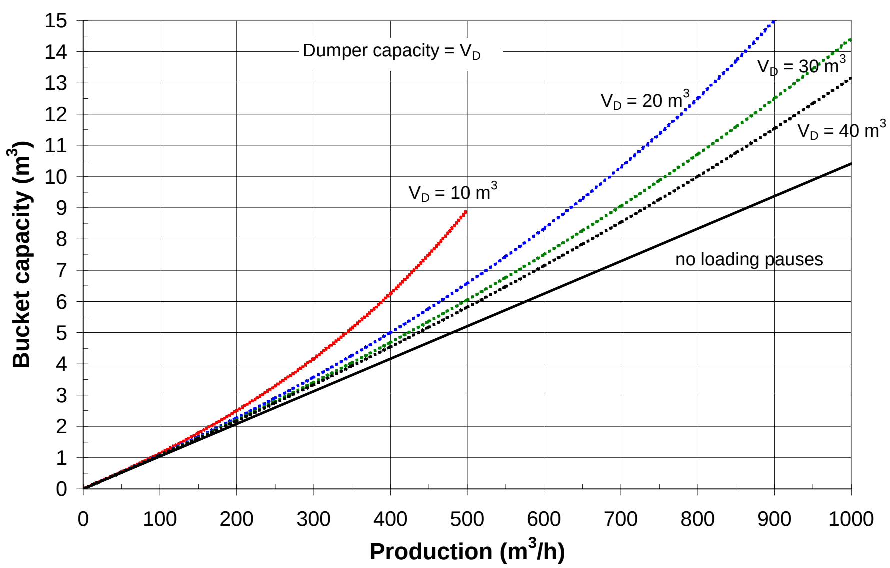


Figure 4. Nomogram linking bucket capacity to truck capacity and production.

3.2. Correlation linking cycle time to shovel features

At the sample sites, for all monitored loading operations, the components of the cycle time (say: bucket filling time, relation to the truck time, bucket empting time, return time) have been measured.

As a general observation, the shortest cycle time are recorded where the shovel stays on the upper bench, with a bench height compatible with the reach of the shovel arm, as shown in figure 5.

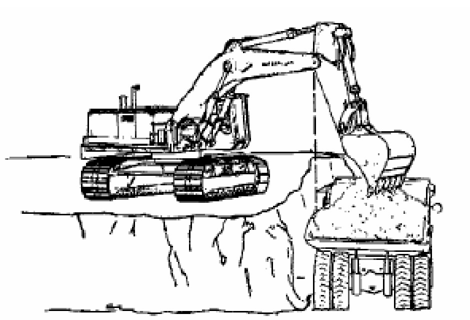


Figure 5. Example of optimal placement of the shovel and truck.

Productivity depends also from the rotation angle, and is critically reduced when rotation angle is over 90°.

The average cycle time has been found to be 22 s for the backhoe shovel and 32 s for the heavier and larger front shovels. A rather poor correlation has been found linking the cycle time to the bucket capacity and to the installed power of the shovel (see figures 6 and 7).

Apparently the cycle time is affected mainly by the volume moved in the cycle, hence by the filling and unloading times.

The features of the truck do not affect significantly the cycle time.

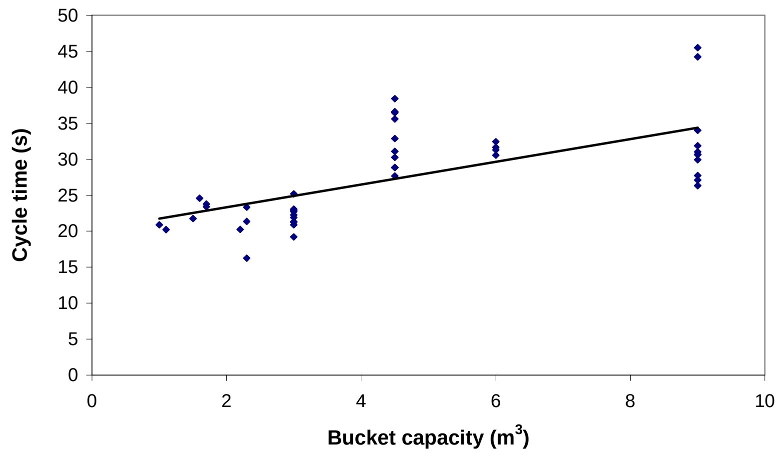


Figure 6.

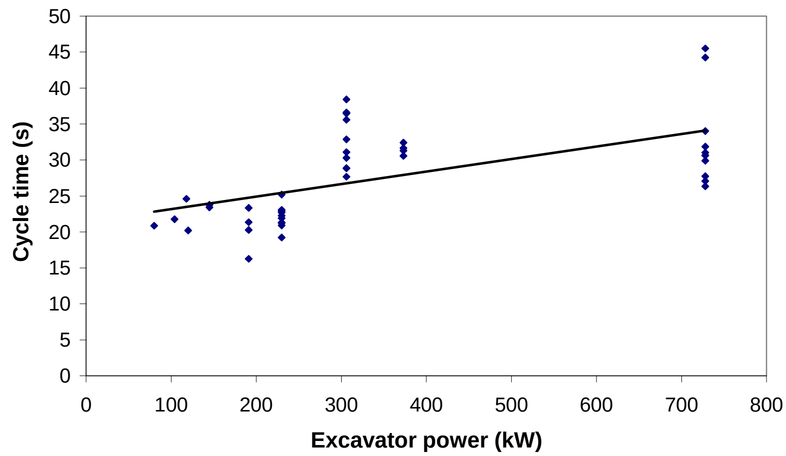


Figure 7.

3.3 Correlation linking the installed power to the bucket and truck volumes

For the shovel-truck system, correlation has been found linking the installed power of the two machines, which could represent a criterion for a preliminary check of the good match of the machinery selected (see figure 8).

The same applies to the correlations found between bucket capacity and truck capacity and truck installed power, and between truck capacity and shovel installed power (see figures 9 and 10).

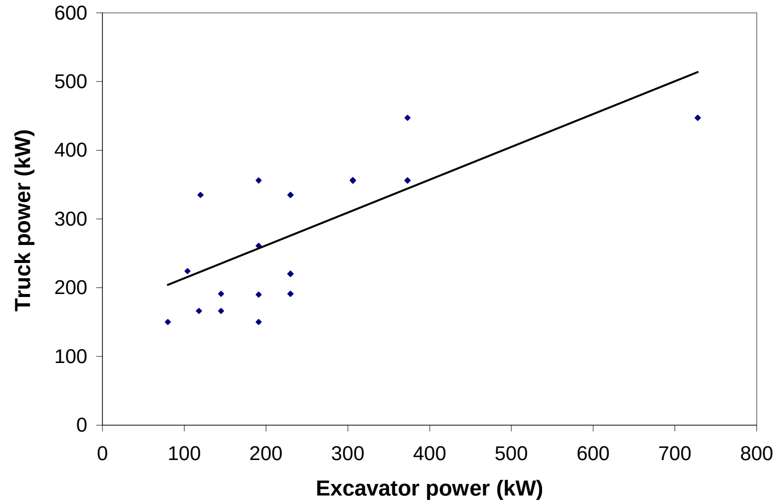


Figure 8.

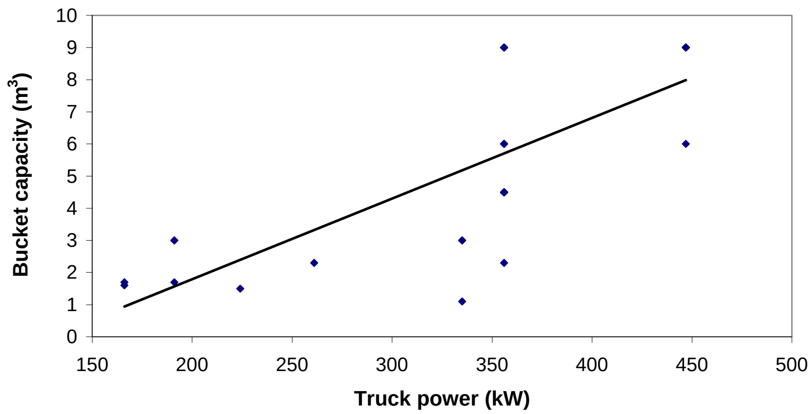


Figure 9.

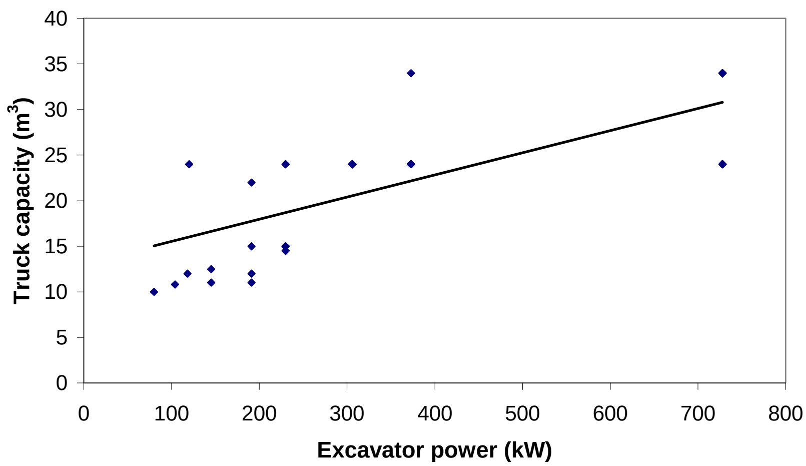


Figure 10.

Indeed, this is an outcome of the power-capacity correlations existing for the two families of machines (see figure 11 and 12).

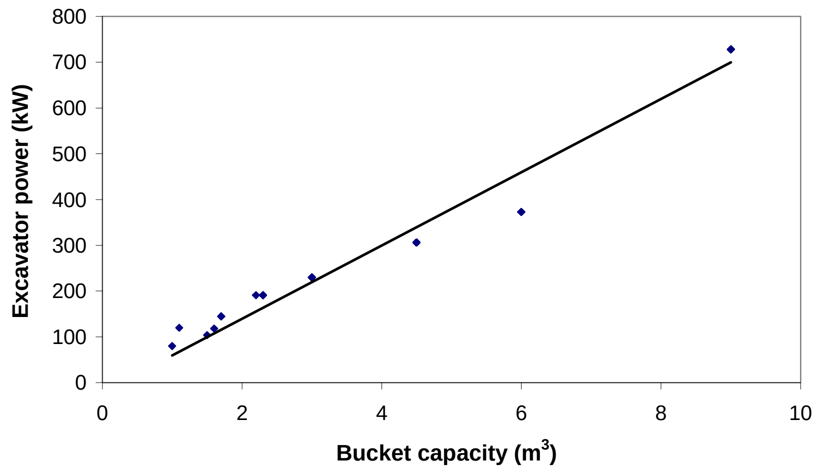


Figure 11.

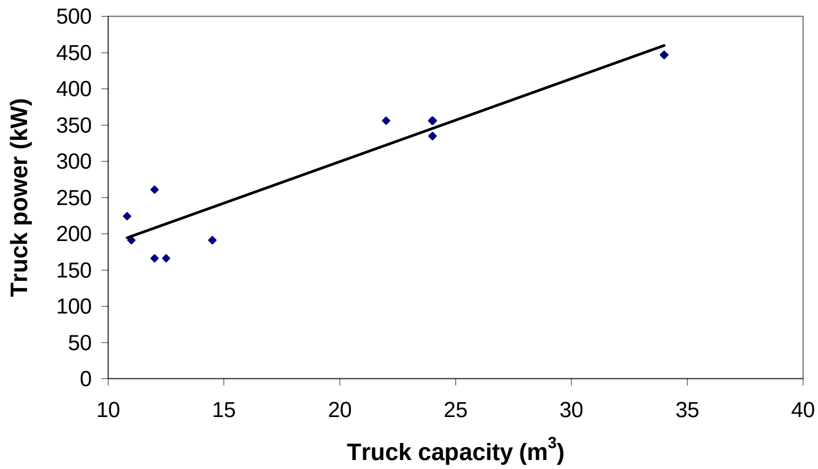


Figure 12.

Confirming literature data (W.J. Martin *et al*. 1982) the backhoe shovels, for the same bucket capacity, are heavier and install more power.

The trend seems to point out that, when front shovels are used, larger bucket capacity are preferred, within the limits posed by machine stability restrictions.

3.4. Hourly productivity v/ bucket capacity correlation

The analysis of the test site data provided a quite good correlation, shown in figure 12, which can be confidently used for a preliminary selection of bucket size for a given productivity.

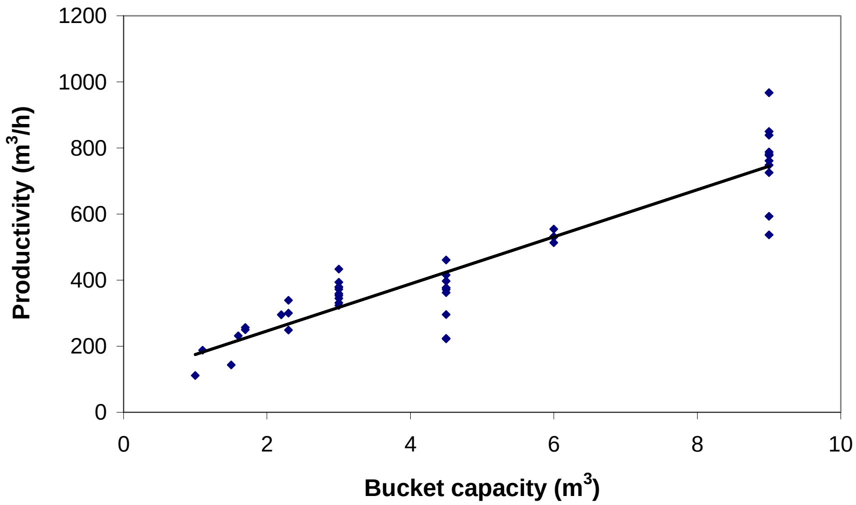


Figure 13.

4. Conclusions

A conspicuous collection of data from test sites made possible an analysis of the main features of the shovel-truck system adopted by mining and quarrying activities in Italy.

A logical sequence to be followed when checking for the optimal match of the shovel-truck system is suggested by the observed correlations:

- on the basis of the required hourly productivity, the bucket capacity is selected and the average cycle time is estimated, according to the suggestions of figure 13 and figure 6;
- the truck capacity is selected on the basis of the bucket capacity, according to the suggestion of figure 2;

- the installed power of the machines are estimated from the bucket and truck capacities, according to figure 11 and figure 12.

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