A COST-BENEFIT ANALYSIS OF TRACKING AND TRACING SYSTEMS IN ROAD CONSTRUCTION

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A major problem in road construction is the lack of timely and accurate information about the location and productivity of equipment. As a result, the productivity rate of certain types of construction equipment is low and equipment has to be hired in from third parties. Lack of co-ordination between the equipment department and the site manager is the major cause of these problems. In this paper, two basic solutions for this co-ordination problem are presented by using the Galbraith' framework. A road construction company can either (1) reduce the need for information processing between the equipment department and the site manager or (2) increase its capacity to process information. The focus of this paper is on the second mechanism by analysing the role of tracking and tracing systems in increasing the capacity of information processing. The paper provides an improved understanding of the factors determining the costs and benefits of these systems in road construction. This cost-benefit analysis is based on the three elements of a tracking and tracing system: collecting, transmitting and analysing data. Empirical research was conducted at one of the biggest road construction firms in the Netherlands. The study shows that investments in tracking and tracing systems can be very efficient for equipment that has to be rented frequently.

Keywords: construction equipment, co-ordination, cost-benefit analysis, information systems.

INTRODUCTION

The construction industry is characterized by continuously changing production locations. When a project is finished, people and equipment move to another construction site (Agapiou *et al.*, 1998; O'Brien *et al.*, 1995). A major problem in road construction is the lack of timely and accurate information about location and productivity of the equipment at the different sites. Equipment gets lost, is stolen or transported from one site to another without informing the equipment department. Because of this lack of transparency, the planning of equipment cannot be optimized. As a result, productivity rates of certain types of equipment are low (idle periods of equipment), work processes are delayed (equipment is not available when needed) and delivery of equipment to the construction sites is done on an ad hoc basis.

In the transport sector, however, various technologies are used for tracking and tracing cars, trucks, containers, etc. Participants of the logistic chain are informed about the current status of their transport continuously or only in case of errors or delays, if they wish. The information is based upon larger transport units such as a truck, container, or parcel but can also be retrieved on a per item basis. Tracking and tracing systems lead to better use of transport facilities as well as minimizing the number of wrongly directed transports (Loebbecke and Powell, 1998). Timely and accurate information about delays or missing items reduces searching costs and post-delivery analysis of

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transport. Similar advantages may also be realized in road construction. By applying tracking and tracing systems, equipment and machinery on different construction sites may easily be located. More transparency in location and productivity facilitates planning and control and decreases the need to hire equipment from third parties. Moreover, the routing of equipment between the different construction sites can be improved.

The first objective of this paper is to relate tracking and tracing systems to the existing broader literature on organizational design by using the framework of Galbraith (1973; 1974). Major issue of this framework is the effectiveness of alternative co-ordination strategies. In this paper, it is assumed that tracking and tracing systems are one of the strategies solving co-ordination problems inside road construction firms. The second objective of this paper is to provide an improved understanding of the factors determining the costs and benefits of the co-ordination strategy of tracking and tracing in road construction. Estimating these costs and benefits is very difficult. While accepting that such calculations are approximate, this paper provides elements of such a cost-benefit analysis based on the three elements or layers of a tracking and tracing system, namely the operational, the communication and the interpretation layer.

Empirical research was conducted in the Dutch building industry. Data for this study were collected by interviews with managers of one of the biggest road construction firms in the Netherlands. Studies of documents used for the planning of road construction projects of this firm were a second source of data. In order to improve reliability interview reports as well as the final report were sent to the interviewed persons. The major reason for doing a case study was the importance of studying costs and benefits of tracking and tracing systems in their real-life context (Yin, 1994). Another reason for using this research methodology is the exploratory nature of this study. The outline of this paper is as follows. In part one, tracking and tracing systems are related to the existing broader literature on organizational design by using the Galbraith' framework. In part two, attention is devoted to basic elements of tracking and tracing systems. A cost-benefit analysis of tracking and tracing in road construction is presented in part three. The paper is finished off with conclusions.

EQUIPMENT CONTROL AND CO-ORDINATION

Co-ordination inside organizations

A major cause for the lack of transparency in location and productivity of road construction equipment is the lack of co-ordination between the equipment department and the site manager. The equipment department is informed too late about the planning of construction projects and equipment needed. Because of this lack of information, it is difficult to anticipate on disturbances. Volatile changes in supply and demand of equipment results. Information about available equipment becomes unreliable. The lack of communication between the equipment department and the site manager is caused by the dominant role of this manager in organizing and planning road construction projects. For the site manager, the progress of a project has the highest priority. Slack in the use of equipment is of minor importance. For that reason, equipment is sometimes ordered weeks in advance in order to be sure it is available on the site when needed (the machines are idling for weeks). For the same reason, equipment is taken from one site to the other without informing the equipment department.

Tracking and tracing (T&T) may solve these problems by providing information about location and productivity of the road construction equipment used. T&T systems can be related to the existing broader literature on organizational design, by focusing on the issue of effective co-ordination strategies within firms. Galbraith (1973; 1974) is probably the best known author on the co-ordination of organizational activities. The central idea is that information can reduce uncertainty: ‘the greater the task uncertainty, the greater the amount of information that must be processed among decision-makers during task execution in order to achieve a given level of performance’ (Galbraith, 1973).

Galbraith discusses a number of co-ordination mechanisms, which can help to share information. The higher the need for information, the more different co-ordination mechanisms are required. When there are uncertainties associated with the tasks, then information processing is referred up the hierarchy to a level where an overall perspective exists. This is the traditional exception-based hierarchical decision making. Such hierarchical decision making can handle only a limited amount of uncertainty. If the uncertainty exceeds the capacity of the hierarchy, then targets or goals have to be set for the various tasks, making them somewhat independent. The co-ordination has moved from a procedure orientation to a result orientation.

We will now review co-ordination mechanisms of Galbraith in more detail and relate these mechanisms to the planning and control of road construction equipment. Using the framework of Galbraith (1973) two co-ordination mechanisms can solve the planning and control problems mentioned. A road construction company can either (1) reduce the need for information processing between the equipment department and the site manager or (2) increase its capacity to process information. The need for information processing can be reduced by increasing slack resources or by creating self-contained tasks. The processing of information can be increased by creating lateral relations or by investment in a vertical information system.

Less need for information processing

In the Galbraith’ framework increasing slack resources reduce the need for information processing. In fact, site managers in road construction industry use this co-ordination mechanism. On construction sites, small equipment is often used only for a few hours per day. Moreover, about 10% of this equipment ‘disappears’ each year, which means it is stolen or stands idle somewhere or is sent to another site without informing the equipment department. Because of this ‘disappearance’, the productivity rate decreases and equipment has to be hired from external parties. This slack in equipment use replaces the need to process the information required for optimal equipment planning by the equipment department.

A second mechanism reducing the need for information processing is the introduction of ‘self-contained tasks’. In this study, one can speak of ‘self-contained tasks’ when site managers get budget responsibility for the use of equipment. In that case, it is expected that slack in equipment use decreases. Site managers will try to keep productivity rates high by, for example, the integration of the planning of different construction projects. Figure 1 shows that productivity rates of equipment are often low at the start and the end of a construction project. By integrating projects, productivity rates will increase. The budget responsibility for equipment use, interpreted here as the self-contained tasks of the site manager, replaces the need to process information with the equipment department. Equipment control is decentralized. Site managers control and plan the equipment independently from the equipment department.

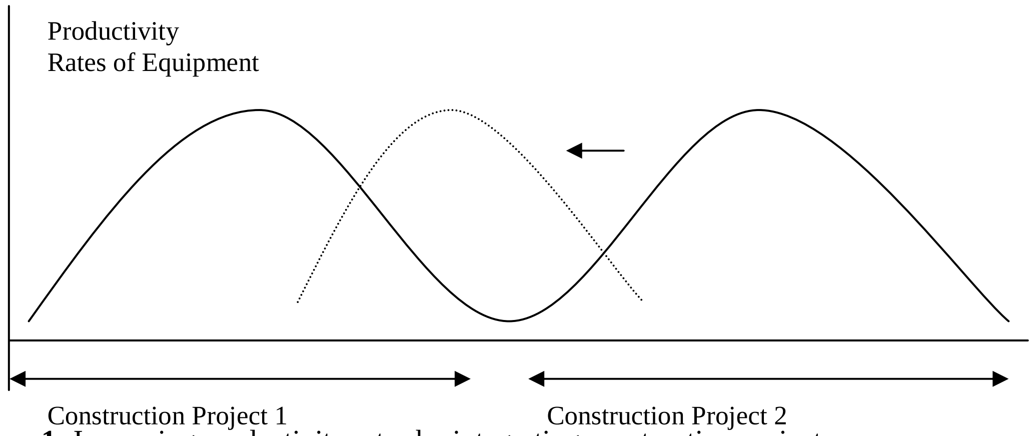

Figure 1: Increasing productivity rates by integrating construction projects

More capacity for information processing
An alternative approach for a road construction firm is to increase its capacity to process information. This information-processing capacity can first be increased by creating lateral relations. Direct contact, liaison roles, task forces and permanent teams are examples of this strategy. In our study, direct contacts between site managers and the equipment department will provide improved information about demand and supply of road construction equipment. The time for preparing orders and delivering equipment to the sites and productivity rates will increase.

The information processing capacity can also be increased by investments in *vertical information systems*. The demand for information-processing capacity that arizes from uncertainty frees the organization to be able to react to unforeseen events. In a highly specialized organization, it may be difficult to have all specialized groups react in a co-ordinated manner. An information system may increase the speed and amount of information that can be exchanged (Voordijk, 1999). The introduction of satellites, information computer networks, and T&T systems can increase the information-processing capacity of an organization. In the next sections, we will analyse T&T systems as a co-ordination mechanism solving the planning and control problems by increasing the information processing capacity.

ELEMENTS OF TRACKING AND TRACING SYSTEMS

Tracing and tracking (T&T) is defined as ‘the ability to ascertain the location and/or status of a given consignment, fleet, equipment and/or shipments’ (European Commission, 1999, 11). The concepts tracking and tracing are defined more specifically as follows:

- *Tracking* is systematically monitoring and recording the *present* location and status of a transaction. It refers to the ability to get information on the actual status or condition of a transaction.
- *Tracing* is finding and reconstructing the transport *history* of a given transaction. T&T information has usually value for an actor, if he can react to or is informed about a changing status in time.

T&T can either be done at fixed times (the geographical position of an item is measured) or at fixed locations (the time is measured that an item passes). The main difference is here, that in the latter case information is provided by the last available observation or measurement of the status/condition of the transaction. Tracking at fixed times uses some form of wireless (data) communication. In a T&T system several technologies are applied and integrated. Different types of T&T systems reflect different technology combinations or alternative *configurations* of these systems. Each T&T system, however, consists of three basic elements or layers (see Figure 2).

The *operational layer* consists of technologies used for identification and gathering of data. These technologies are widely available. For identification the main components are tags and chip cards. A tag is a unit that is fitted on a vehicle, wagon or container and can be read form a distance using radio frequencies or satellites. Both the reductions of costs for (i.e. satellite and GSM) communication and components in this layer will have a positive effect on the development of T&T. On the other hand, the dynamics and variety in types and alternatives of these technologies cause uncertainty about the long-term developments.

The *communication layer* consists of several types of communications networks focusing on data transmission. Satellite based systems play a major role in the mobile communication needed for positioning. The quality of the services has risen strongly in the last decade, and the tariffs have decreased strongly. At the same time the European telecommunication market has been liberalized and the mobile communication market became booming business. Within this layer the increased penetration of Internet is the most important development. The open formats, low investment and operational costs are the main benefits of this technology.

The mayor type of technology at the *interpretation layer* is the software to process and analyse the T&T data gathered from the physical operations. Applications are mainly related to the planning and administration of transport operations. Material and equipment management belongs to this layer, but examples of applications in this area using T&T data are still limited.

In nearly all T&T experiments and systems road transport is involved (European Commission, 1999). As the value of the goods and time is usually higher than for other inland transport modes, road transport was leading in the development of T&T systems. The in-house systems of express delivery companies were the first group of T&T systems developed and are based on barcode scanning at transhipment points. In the express delivery market, time and optimized planning are crucial in order to provide an on-time delivery for customers. These T&T systems were in the first place developed to optimize internal operations. Therefore the scope was limited to the depots, warehouses and equipment of the company itself. Most of the express companies extended their system in order to incorporate other stages of the transport transaction and offered access to the T&T data to their customers. The companies equip drivers with barcode readers (for example pen-keys) in order to register the final delivery to the consignee. The introduction of tag technology in transport during the last ten years, offered opportunities for T&T of containers. Pioneer projects faced high costs for communication, tags and reader systems. Prices for these components have dropped during last years, but costs are still major barriers for a large-scale introduction of T&T systems for inter-modal transport.

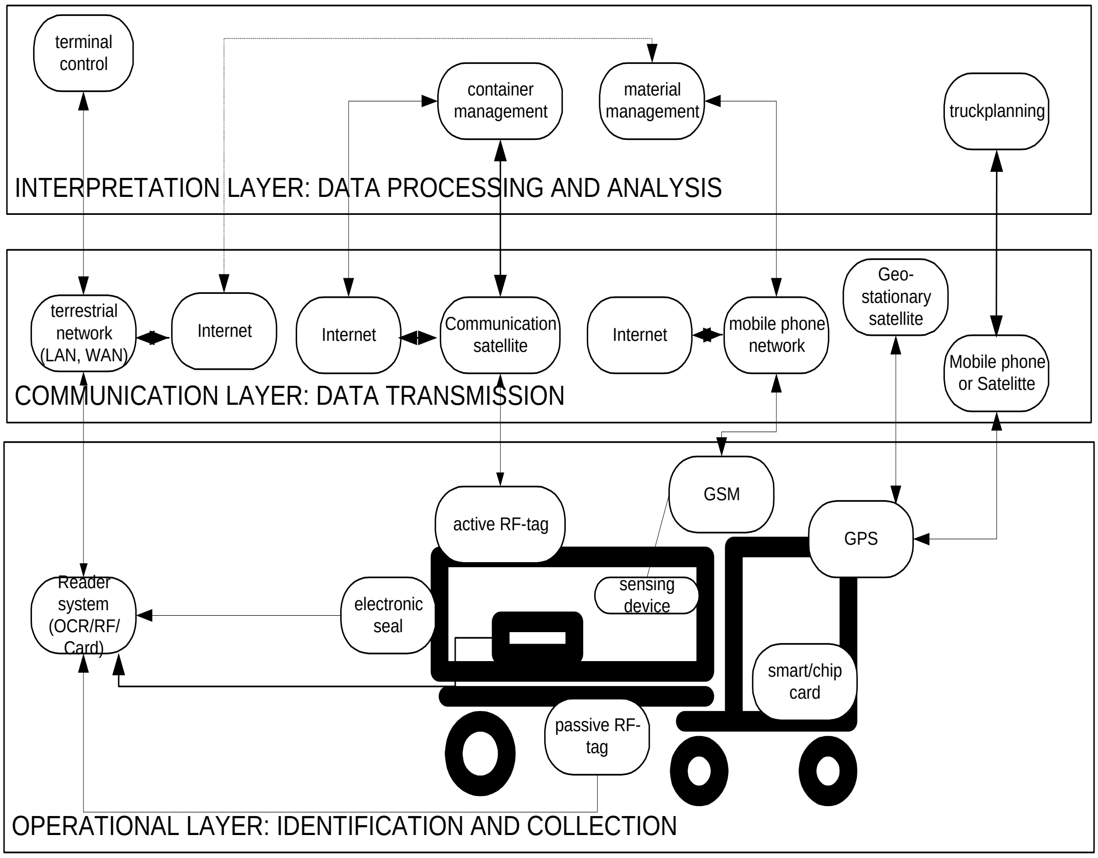

Figure 2: Overview of T&T technologies

Failure factors can be found on all three layers of T&T systems. On the operational layer it is stated that investments for collecting data are quite high, especially taken into account the risk of loss and damage. Also the enormous variety of products and techniques makes it difficult for organizations to choose. They are afraid to bet on the wrong horse. At the communication layer the variety of products leads to a lack of interoperability, especially for load units that travel worldwide. Also the quality of communication at many locations is poor. At the interpretation layer many organizations are still reluctant to share data. If these organizations are willing to share data it appears to be a tough job to agree on shared interpretations of the information sent and of the value of this information.

Success factors can also be noticed on the three layers. At the operation layers the technology is becoming better and cheaper, which also accounts for the communication layer. On the interpretation layer one can observe that more companies see the need to co-operate on sharing data and that slowly progress is made in the field of system architectures, reference models, user groups, implementation guidelines and comparison are made of best practices.

A COST-BENEFIT ANALYSIS OF TRACKING AND TRACING

A major objective of this study is to provide an improved understanding of the factors determining the costs and benefits of tracking and tracing in road construction. Empirical research was conducted at one of the biggest road construction firms in the Netherlands. For this case study, data were collected by interviews with managers of this firm. According to these managers, equipment is a critical resource in the execution of road construction projects. The equipment fleet represents the largest long-term investment in a road construction company. Consequently, equipment management decisions have significant impacts on the economic viability of construction firms (Schaufelberger, 1999).

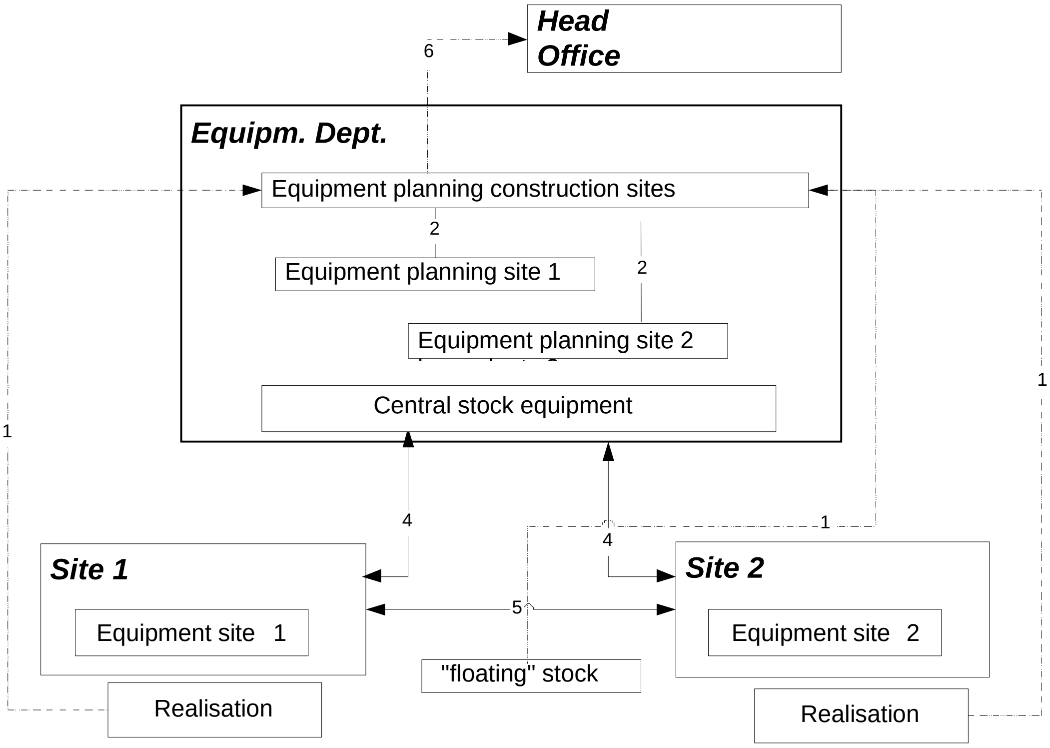

Figure 3: Tracking and tracing in road construction

In general, two categories of road construction equipment can be identified:

- Small equipment (initial investments less than 25,000 Euro): this equipment is often used before roads are paved. The productivity rate of this type of equipment is often very low. Examples are hand-operated ram compactors and steel-drum compactors.
- Large equipment (initial investments more than 25,000 Euro): specialized equipment, for example paving machines used to spread and compact plant mix pavements, asphalt distributors and aggregate spreaders. When this equipment is used in the right mix on the construction site productivity rates are high.

By applying tracking and tracing systems, equipment on the different construction sites can easily be located. More transparency in location and productivity of the equipment facilitates planning and control and decreases the need to rent equipment from third parties. Moreover, the routing of equipment between the different construction sites can be improved. Other benefits are less searching costs when equipment is lost or stolen. Ideally spoken, the equipment department could use T&T in order to optimize equipment management and control as shown in Figure 3.

The costs of using a T& T system in road construction can be related to the different layers of such a system:

- *Identification and gathering of data:* the costs are low when standard hardware and software are used. In the case of road construction, sensors and/or tags have to be developed in order to monitor the time the equipment is used on the site.

- *Transmission of the data collected:* the costs of communicating the data collected on the construction site to the equipment department. These costs depend on the number of transactions and the quantity of data sent at each transaction.
- *Interpretation and analysis of the data:* these costs are low when the information technology needed is available at the firm. In that case, additional investments are not necessary.

Certain cost categories are presented in more detail in Table 1.

Table 1: Costs of tracking and tracing in general

	Investments	Costs (yearly)	Costs (one transaction)
Tags for identification	5 to 75 Euro		
Readers	In case of fixed position about 1000 to 5000 Euro		In case of satellite communication, about 0.5 to 13 Euro for each transaction
Transmission of data			About 0.25 Euro for each transaction
Information technology for analysis and interpretation	Hard + software	User training	

Using the framework of the three layers, costs and benefits of applying T&T systems in road construction are analysed for different types of equipment.

One type of equipment analysed is the hand-operated plate compactor. This type of equipment is analysed because of its very low productivity rate. Compactors are used for the mechanical densification of soil in order to improve its strength (Schaufelberger, 1999). The construction firm of our case study possessed different types of hand-operated plate compactors that are used on different construction sites. Productivity rates at the different sites are often not higher than 20%. Theoretically, the capacity of one compactor is enough to replace five others. The costs and benefits of using T&T systems for a group of five compactors of the same type are presented in Table 2. The major benefit of using a T&T system is that these compactors don't have to be rented anymore (the money saved in this case is about 30,000 Euro each year). Major costs are the initial investments in developing sensors and software because these products are not standard available (about 10,000 Euro). The transaction costs from site to office are about 13,000 Euro yearly. At the construction firm analysed, the software needed to analyse the data collected is available. Additional investments are not necessary.

Table 2: Cost-benefit analysis of five compactors (in Euro)

		2001	2002	2003
Benefits	Rent savings	30,000	30,000	30,000
Costs	Sensors + software	10,000		
	Transaction costs	13,000	13,000	13,000

Costs and benefits of applying T&T on a steel-drum compactor are presented in Table 3. The costs of renting this equipment could be saved when a T&T system is used (about 10,000 Euro yearly). Major costs are here again the initial investments in developing sensors and software.

Table 3: Cost-benefit analysis of a steel-drum compactor (in Euro)

		2001	2002	2003
Benefits	Rent savings	10.000	10,000	10,000
Costs	Sensors + software	6,000		
	Transaction costs	2,500	2,500	2,500

CONCLUSION

In this study, T&T systems are related to the broader literature on organizational design by using the framework of Galbraith (1973, 1974). This framework shows that co-ordination problems between the equipment department and the site manager can be solved either by (1) *reducing* the *need* for information processing or (2) *increasing* the *capacity* to process information. These mechanisms fit with a decentralized or centralized planning and control of equipment.

Creating self-contained tasks reduces the need for information processing. In this study, one speaks of 'self-contained tasks' when site managers get budget responsibility for the use of equipment. In that case, it is expected that slack in equipment use decreases. Site managers try to keep productivity rates as highly as possible. This approach fits with a decentralized planning and control of the equipment. The self-contained tasks of the site managers replace the need to process information with the equipment department. They manage their own sites independently from the equipment department. Of course, this strategy of reducing the need for information processing may incur high opportunity costs from non co-ordination. Thus, reducing information needs must be balanced with the return of co-ordinating the activities.

An alternative approach for a construction firm is to increase its capacity to process information. Direct contacts between site manager and equipment department improve the quality of information about demand and supply of equipment. The capacity to process information can also be increased by investments in information systems. An information system may increase the speed and amount of information that can be exchanged. The organization is able to react faster to unforeseen events. The introduction of T&T systems is an example of this co-ordination strategy. Implementing T&T fits with a centralized planning and control of equipment by the equipment department. Major benefit of T&T in road construction is a more efficient use of equipment owned by the construction company. The initial costs for placing T&T systems on small equipment is quite high. Moreover, increased productivity rates result in higher transportation costs: equipment has to be transported more often from one site to another. It can be concluded that initial investments in T&T systems can be very efficient for equipment that has to be rented frequently. For smaller equipment, placing passive tags needed to localize this equipment is sufficient.

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