A SYSTEM DYNAMICS MODEL TO ASSESS THE OPTIMAL NUMBER OF CREWS FOR CONDUCTING AIR CARGO OPERATIONS

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Abstract:
Notwithstanding the extensive studies involving the cargo terminal operations issues, a knowledge gap emerges. Literature has focused its research on the manpower assignment and the crew scheduling problems, whereas the determination of the cycle time of the activities to be performed, and, as a consequence, the job lead time, has been often neglected. Thus, filling such a gap is the goal of the present paper, which is aimed at developing and testing a model for defining the cycle time involved in air cargo terminal activities and the corresponding job lead time, in relation to both job characteristics and terminal resources. The causal diagram that depicts such relations is built and applied to a real process. Then, the assumptions based on the model are validated by means of data gathering and statistical analyses (ANOVA).

Key Words: Air cargo terminal, Activity cycle time, Job lead time, ANOVA

Introduction

In recent years, air transport has become one of the main modes for global freights transportation. Such a phenomenon is due to several reasons. From an economical point of view, according to the explanations proposed by (Yuan, Low, & Ching Tang, 2010), the change in consumption habits, entailing the shortening of product life cycles, can be pointed as enhancing the importance of just-in-time logistics and the need of fast transportation mode. From a management point of view, as supply chains have become global, the need of sourcing products and parts from allover the world, while not increasing the delivery time, has involved the need of a fast transport mode, once more. Of course, many other reasons, as the development of e-commerce may have affected and are going to influence the use of such a transport mode (Zhang, 2003). Due to these reasons, air cargo industry has become the fastest growing sector in the dynamic freight market (Coyle et al., 2003), and the forecasted growth rate of 5.8% per year over the next 20 years recalled by (Azadian, Murat, & Chinnam, 2012) hints at the increase of its importance.

One of the direct consequences of such a phenomenon is the increase in number of the air cargo handling companies (Coyle et al., 2003), and, as a result, of the competition within the air cargo sector. Such a high pressure on handling companies is leveraged, on the one hand, by the fact that customers request shorter and shorter lead time and, on the other hand, by more and more unpredictable demand. In order to survive in such a context, air cargo terminals address the challenge to handle large volumes of items efficiently and responding quickly to customer demands (i.e. ensuring both efficiency and effectiveness at the same time is the main issue) (Taylor, Choy, Chow, Poon, & Ho, 2012).

How can air cargo terminals decrease operating costs while maintaining customer service levels (i.e. restrained lead time)? In last years Literature has addressed the problem. In particular, researches on air cargo operations have pointed manpower costs as the largest part of all operating costs, and, consequently, the efficient management of manpower resources has been extensively studied (Rong & Grunow, 2009). Among the others, the crew scheduling planning problem has been broadly reviewed. Several approaches for solving the problem starting from the terminal manpower requirements (i.e. the number of crews needed within a certain time horizon) have been suggested (Yan, Chen, & Chen, 2006b), (Yan, Chen, & Chen, 2006a), (Rong & Grunow, 2009).

How to determine optimal terminal manpower requirements? Notwithstanding the extensive study of the cargo terminal operations problem, Literature lacks in the requirements determination. Nevertheless, properly assessing optimal manpower requirements is paramount to ensure both efficiency and effectiveness. As a matter of fact, in air cargo terminals the crews are usually composed of temporary workers. Every week the air cargo handling company requests to temping agencies a certain number of temporary workers, which depends on the number of crews needed in that week. So if such a number is overestimated or underestimated, despite the crew scheduling process, the air cargo handling company will incur higher costs or will not be able to face the customers demand respectively.

General personnel scheduling is frequently encountered in literature, and it can be defined as the problem of assigning a set of tasks to be performed in a given planning horizon to a group of workers, such that each crew does not exceed a limit on the total time it can spend working (Beasley & Cao, 1996). (Ernst et al., 2004) develop an exhaustive problem taxonomy and problems definition, providing a general framework for classifying much of the effort that has been carried out in the area of personnel scheduling. According to the authors, several application areas can be identified and, among them, the air cargo terminals are pointed. According to them, demand has to be first modeled determining how many staffs are needed at different times over some planning period. With reference to crew demand,(Ernst et al., 2004) state the importance of including a demand modeling step, even though many researches assume demand as either given or easily obtained and others refer to either forecast or heuristic models. Caprara et al. (2003) propose an approach that finds the solution of the manpower management problem in two steps. The determination of the minimum number of employees and the working days for each employee has to be first performed, then, the assignment of the duties to each employee has to be carried out. In such a case, manpower requirements are partially determined. Again, the authors do not completely perform the determination of manpower requirements. (Suryadi & Papageorgiou, 2004) deal with the allocation of maintenance crews to maintenance activities, and they address the problem applying mixed-integer non-linear programming. The authors exploit the statistic nature of equipment failure, and the content of work required in a certain period of time is determined by the piecewise constant function of the units failure rate. As a matter of fact, the presented approach is limited to a maintenance context, and not applicable to an air cargo one.

According to the review performed by (Ernst et al., 2004), personnel scheduling is already well established in the transportation sector in general and in the aviation industry in particular, and air cargo terminals crew scheduling is a widely discussed topic. Personnel scheduling bases on both the determination of the total content of work and the design of efficient assignment. With reference to the first sub-topic, the one investigated by the present research, both (Nobert & Roy, 1998) and (Rong & Grunow, 2009) make use of "demand leveling" to move a certain amount of freight service away from the peak times avoiding idle capacity before determining manpower requirements. On the other hand, according to (Nobert & Roy, 1998), since shipments' characteristics (e.g. weight, number of pieces per shipment, handling unit) vary often, work standards are meant to be difficult to obtain, resulting in incorrect total content of work. (Rong & Grunow, 2009) distinguish service demand in build-up and break-down in the presented model. In the presented case study although demand of the outbound and inbound cargo in each hour is specified, time consumption parameters are not defined, hiding how to find the total content of work out.

As system dynamics (hereinafter SD) models are proved to be appropriate for studying manufacturing systems, offering lens on operations management systems (Georgiadis & Michaloudis, 2012) (Größler, Thun, & Milling, 2008), and, to our knowledge, the problem of the total content of work determination has not been solved, the present paper is aimed at developing a SD model to fill the above mentioned knowledge gap.

According to the proposed model, the total content of work within a certain time horizon depend on the cycle times characterizing the activities of the air cargo terminal operating process that must be executed for handling the jobs (i.e. the customer orders), which fall on the considered time horizon. In turn, the content of work of a job, which is approximated by its lead time, depends on both job characteristics and manpower involvement. The proposed model has been applied to a real-world terminal cargo managed by an Italian handling company with the aim to study the export process.

The paper is organized as follows: Section 2 outlines the proposed model; Section 3 describes the empirical case study the model is applied to and its validation by means of analysis of variance (hereinafter ANOVA); Section 4 provides concluding remarks and future research steps.

The proposed model

The aim of the proposed model is to express the relationships between both job characteristics and terminal resources and manpower requirements, by developing a causal diagram.

Variables and relationships

The independent variables of the proposed model refer both to job characteristics and to cargo terminal manpower involvement. With reference to job characteristics, the considered variables are:

- number of packages: the number of packages that compose the job;
- type if vehicle: the mean of transport where packages are loaded on;
- packages position: how the packages are positioned on the mean of transport;
- pallet height;

With reference to cargo terminal decisions, just one variable is considered:

- number of operators: the number of operators in the crew (i.e. working on the same job at the same time);

As the dependent variable of the proposed model is the lead time of the job and it equals the sum of the cycle times of each activity, the system variables should define the cycle times.

A causal diagram outlines the relationships between the independent and the dependent variables. In the diagram, system variables are impacted by job characteristics and/or cargo terminal facilities, impacting themselves on the lead time of the job. Whether when a variable is increasing/decreasing the impacted one is increasing/decreasing accordingly the impact is ‘positive’ or, on the contrary ‘negative’.

Hypothesis

The system under consideration is an air cargo export process. The latter is composed of five subsequent activities: truck unload, control, pallet preparation, positioning and covering. For each job, all the activities have to be carried out. For each activity, its cycle time determines the amount of time needed by a crew to carry it out.

This model describes the relations between the independent variables and the lead time of the job. Based on the above hypothesis, we develop the causal diagram in figure 1.

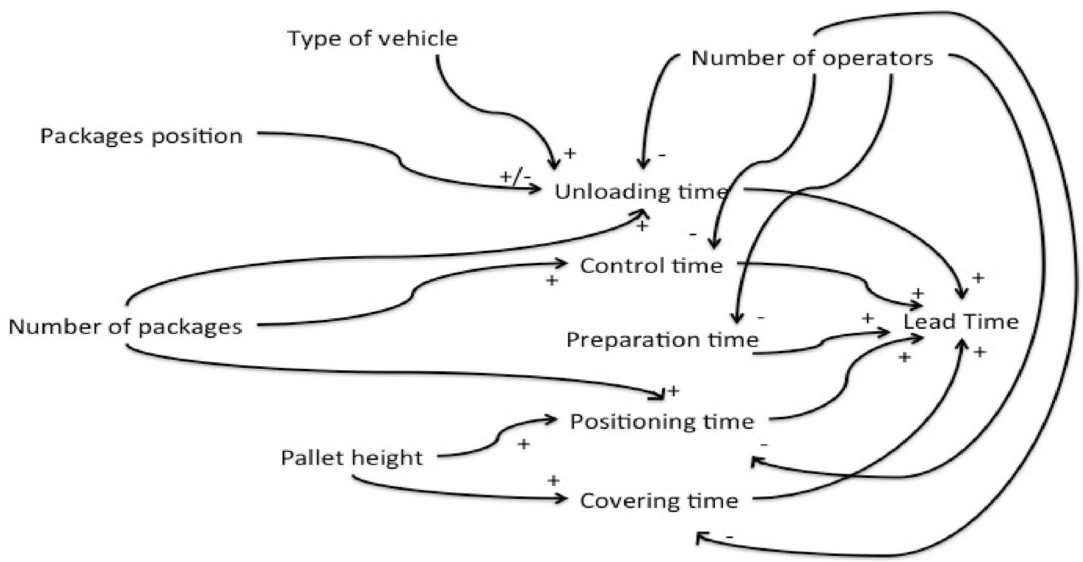

Figure 1 - Proposed model (causal diagram)

Model description

We will outline the effects of the decision variables, which are independent, on the dependent variable (i.e. lead time). In particular, as stated above, the independent variables are 'number of packages', 'number of operators', 'type of vehicle, ' packages position', and 'pallet height'.

Starting from describing in detail the relations for the 'number of packages', we define 'unloading time' as the amount of time it takes to empty the vehicle. By definition, the higher number of packages the truck transports, the higher unloading time. Thus, in our opinion, the 'number of packages' positively influences 'unloading time'. Similarly, the variable 'number of packages' positively influences 'control time', which deals with the amount of time needed to control the arrived packages. With reference to 'positioning time', by definition, the higher number of packages to be positioned, the higher positioning time. The latter is defined as the amount of time needed to place all the packages on the pallet, so that they can be loaded on the air cargo. Again, in our opinion, the variable 'number of packages' positively influences 'positioning time'. Summarizing, the 'number of packages' positively influences 'unloading time', 'control time', and 'positioning time'.

The 'number of operators' has an impact on 'unloading time': when the number of operators in the crew increases, the 'unloading time' decreases. Thus, the model represents a negative influence. Similarly, 'number of operators' negatively impacts on 'control time' and 'positioning time'. With reference to 'preparation time', that is the amount of time needed to arrange the pallet where the packages are then placed, it decreases when the number of operators in the crew increases. The covering of the pallet, that requires a 'covering time', takes less time when the number of operators in the crew increases. Summarizing, negatively influences 'unloading time', 'control time', 'positioning time', 'preparation time', and 'covering time'.

The 'type of vehicle' is involved just in the vehicle unloading activity. In our opinion, as different vehicles have different characteristics (e.g. dimensions), these influence the 'unloading time'. Defining a vehicle ranking on their dimensions, and assuming that in a bigger vehicle a higher number of packages can be contained, it is reasonable to state that unloading a van would take less time than unloading an engine. Thus, the 'type of vehicle' influences 'unloading time' positively.

When packages to be exported are loaded on the vehicle, their optimal positioning is not always respected. Thus, whether 'packages position' is not correct, the 'unloading time' increases, while, whether they are correctly positioned the 'unloading time' decreases. Thus, the 'packages positioning influences 'unloading time' positively or negatively.

With reference to 'pallet height', as it increases, the time to place an additional package to the others increases (i.e. 'positioning time' increases). It is reasonable to assume that placing packages at a low level is easier than placing them in a high position. Thus, 'pallet height' positively influences 'positioning time'. Similarly, it is reasonable to assume that covering a high pallet is more difficult (i.e. involves more time) than covering a lower one. Summarizing, 'pallet height' positively influences both 'positioning time' and 'covering time'.

Model validation

The causal diagram presented in figure 1 is validated in the next paragraphs by studying through data gathering and ANOVAs the effects of each independent variable on the state variables.

The validation procedure

The validation phase is performed by gathering as many activities cycle times as it is enough to perform statistical analyses. Moreover, the cycle times are gathered throughout the twenty-four hours of the day, so that all the situations are covered. The one-way ANOVAs on the data collected are performed by means of Minitab statistical software. The threshold p-value is set equal to 0,05 (5%). Thus, whether the p-value is lower than the threshold the variable is meant to influence statistically the amount of work of micro phase.

ANOVAs results

For each activity, the ANOVAs deal with contents of work and changes in supposed influencing variables. Thus, the results of the analyses include: the variables considered as influencing according to the model, the average contents of work, their standard deviation, the numbers of measurements and the calculated p-values.

Since all the activities are analyzed through the same procedure, an example of ANOVA is presented below (table 1, table 2, table 3, table 4, and table 5), while a results summary for all the activities is presented. The example deals with the "unload" activity, as it is the most representative case. According to the proposed model, four variables influence ‘unloading time’: (i) type if vehicle; (ii) number of packages; (iii) number of operators; (iv) packages position.

Table 1 Example of ANOVA on Type of vehicle

Type of vehicle	Content of work mean [minutes]	Content of work standard deviation [minutes]	# Measurements	p-value	Statistical relevance
Van	4.35	3.41	26	0	YES
Engine	8.72	7.39	60		
Tractor-trailer	21.65	15.21	49		

The ANOVA confirms the relation modeled, as the content of work is higher when the type of vehicle to unload has bigger dimensions.

With reference to ‘number of packages’, as the types of vehicles differ in capacity, the variable is presented in relation to each type of vehicle.

Table 2 Example of ANOVA on Number of packages

Type of vehicle	Number of packages	Content of work mean [minutes]	Content of work standard deviation [minutes]	# Measurements	p-value	Statistical relevance
Van	1≤n<6	3.52	2.55	27	0	YES
	5<n<11	6.80	5.02	5		
Engine	1≤n<6	3.72	3.10	25		
	5<n<11	9.79	4.34	28		
	10≤n<16	13.67	5.92	9		
	15<n<21	23.00	9.99	2		
	>20	45.00	0	1		
Tractor-trailer	1≤n<6	3.89	1.76	9		
	5<n<11	11.2	4.73	10		
	10≤n<21	21.36	13.6	14		
	20<n<31	31.15	9.62	13		
	30<n<51	44.67	11.02	3		
	n>50	102.50	2.12	2		

Again, the ANOVA confirms the relation modeled (i.e. the content of work increases when the number of packages increases).

With reference to the variable ‘number of operators’, as the types of vehicles differ in dimensions, it is presented in relation to each type of vehicle.

Table 3 Example of ANOVA on Number of operators

Type of vehicle	Number of operators	Content of work mean [minutes]	Content of work standard deviation [minutes]	# Measurements	p-value	Statistical relevance
Van	1	3.83	3.21	24	0.038	YES
	2	9.00	2.82	2		
Engine	1	8.21	6.54	52	0.072	NO
	2	13.50	12.92	8		
Tractor-trailer	1	21.75	22.55	40	0.318	NO
	2	29.30	13.70	10		

In such a case, the ANOVA deny the relation that is proposed by the model (i.e. the negative influence of the variable 'number of operators' on 'unloading time'). In particular, in case two operators unload a van, the unloading cycle time increases with statistical relevance. With reference to engine and tractor-trailer, the cycle time increases as well, but no statistical relevance is registered. The ANOVA results, at first sight, appear nonsense. On the other hand, it is reasonable that two operators unloading packages from a van get in the way each other, increasing significantly the cycle time. With reference to the engine and the tractor-trailer, as the throughput space is larger, the operators working together still increase the cycle time, but not significantly.

With reference to 'packages position', it is not strictly related to the type of vehicle.

Table 4 Example of ANOVA on Packages position

Packages position	**Content of work mean [minutes]**	**Content of work standard deviation [minutes]**	**# Measurements**	**p-value**	**Statistical relevance**
Correct	16.62	11.46	37	0	YES
Not correct	45.17	29.47	12		

The ANOVA confirms that positioning influences the 'unloading time'.

Table 5 provides a summary of the relations between influencing variables and the system variable 'unloading time'.

Table 5 Summary of Unloading time

Variable	**Relation from the model**	**Validated?**
Type of vehicle	Different vehicles have different characteristics (e.g. dimensions), these influence the 'unloading time'	Yes
Number of packages	Positive influence	Yes
Number of operators	Negative influence	No
Packages position	Whether it is not correct, the 'unloading time' increases, while, whether packages are correctly positioned the 'unloading time' decreases	Yes

As previously stated, with reference to the other activities (i.e. control, preparation, positioning, and covering), their summary tables are presented (table 6, table 7, table 8, and table 9).

In relation to 'control time', the positive influence of the variable 'number of packages' in the system variable is confirmed. On the other hand, no statistical difference is registered between one or two operators working on the same job. This can be due to limited the control space.

Table 6 Summary of Control time

Variable	**Relation from the model**	**Validated?**
Number of packages	Positive influence	Yes
Number of operators	Negative influence	No

In relation to 'preparation time', the negative influence of the number of operators on the cycle time is validated.

Table 7 Summary of Preparation time

Variable	**Relation from the model**	**Validated?**
Number of operators	Negative influence	Yes

In relation to 'positioning time', the positive influence of the variables 'number of packages' and 'pallet height' is confirmed by the ANOVA. With reference to the 'number of operators', the negative influence is not significant. This can be due to the amount of time needed to set the positioning, which does not depend on the number of operators involved.

Table 8 Summary of Positioning time

Variable	Relation from the model	Validated?
Number of packages	Positive influence	Yes
Pallet height	Positive influence	Yes
Number of operators	Negative influence	No

With reference to the pallet covering activity, the positive relation identified by the model is confirmed by the ANOVA. With reference to the 'number of operators', the negative influence is not significant.

Table 9 Summary of Covering time

Variable	Relation from the model	Validated?
Pallet height	Positive influence	Yes
Number of operators	Negative influence	No

Conclusions and directions for future research

This paper focuses on topical and current managerial issues. As a matter of fact, air cargo terminal efficiency gained high significance in last ears, due to economical and managerial points of view. With reference to the first, change in consumption habits, entailing the shortening of product life cycles is cited by literature. From a managerial point of view, the enlarging of the supply chains requires faster means of transportation. Thus, the paper is aimed at proposing a model for explaining the relations between both job characteristics and terminal resources and manpower requirements. By performing statistical analyses, i.e. one-way ANOVA, on the activities gathered cycle times, the relations between independent variables and system variables have been studied. On the basis of these, both general and particular conclusions are can be derived from the present research.

Referring to the model, it can be easily validated by means of data gathering and the performing of ANOVA by means of Minitab statistical software. On the other hand, since the amount of data to perform an effective ANOVA is quite high, the data gathering is a time consuming activity. Moreover, as the air cargo terminals are usually in service overnight, the cycle times has to be performed accordingly.

With reference to particular conclusions, the variable influence of the 'number of operators' on the cycle times deserves attention. As it is reasonable to infer that a higher number of operators reduces the cycle times, the ANOVA results deny this statement. In fact, some activities cycle time are disadvantaged from a higher number of operators, because of tight work spaces.

We reckon that the proposed model presents some limitations. First of all, not all the possible independent variables have been identified. Of course, many others influence the lead time of the job. It would be interesting to analyze whether there is a different effect of the lead time (i.e. on the system variables that compose the lead time). We believe these could be further steps of the research.