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PROCESSING AND ANALYSIS OF SHIP-TO-SHORE GANTRY CRANE OPERATOR PERFORMANCE CURVES IN CONTAINER TERMINALS

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Abstract

To describe the performance of skilled operators in the transport sector, curves are used that relate quality of performance to operator arousal level. Though performance assessment has a long history in the aviation and aerospace industries, the use of performance curves is relatively recent in the transport sector.

The rapid advances in technology accompanied by the demand for highly skilled workers also in port operations have resulted in the need for analytical tools geared to enhancing operator performance, reducing fatigue levels and hence the possibility of accidents involving personal injury occurring.

This paper concerns the analysis of performance curves obtained for a ship-to-shore gantry crane operator in a container transhipment terminal: The curves have been plotted for four work shifts and allow to identify the most critical phases in terms of time on shift, in relation to the task performed. The results of the analysis indicate that curve specification for particular job tasks should be done using a simulator, that is able to represent the entire spectrum of operating conditions, including atypical and the less common ones.

Key words: performance operator curves, fatigue, human factors, ship-to-shore crane simulator.

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INTRODUCTION

Human error is a leading contributor to transportation-related safety problems, especially in the maritime transport sector. In fact human error is the cause, or contributor to a large percentage (80%-90%) of accidents occurring in docks. Despite the high degree of automation achieved in recent years in this sector, the human operator continues to play a central role. As in all transport systems, in maritime transport man becomes the pivot around which the system revolves in terms of safety and the *human factors* discipline is central to the design of the system and to the development of its components (Loi, 2004).

Generally speaking, safety is achieved through a combination of active and passive systems.

Passive safety is concerned with devising measures for reducing the consequences of accidents.

By contrast, active safety is concerned with those factors affecting operator performance and the processes underlying human error in task performance.

The human factors discipline plays an important part in active safety and within this area of activity anthropometry and ergonomics are taking an increasingly prominent role. In general operators are analysed by classes or groups of different individuals based on psychophysical, attitudinal and other characteristics.

Unlike the mechanical properties of the human body, human factors that form the basis of passive safety studies, active safety research embraces :

— biodynamics, analysing how man perceives external stimuli, through the senses (sight, sound, touch);
— information theory, that is founded on the knowledge of the mental processes underlying perception, based on which the most suitable ways of transmitting information to human operator are defined;
— decision theory analysing the human decision making processes that produce the most suitable choice.

The combined study of the above three phases provides an understanding of the reasons underlying human error, that can in general can be attributed to:

— inefficient man-machine interface;
— improper task management and operability;
— operator training and limitations (Fadda, 2002).

Human factors are the primary cause of error-induced accidents in port operations. Accident reports tend not to specify the exact type of error. For example, a report issued by Maritime New Zealand (2004) describes an accident involving a ship-to-shore crane when the spreader collapsed as a result of the support cables snapping. It was not possible to identify the exact cause of the accident though an *"error of judgement"* by the crane operator was perceived as the cause. The report provides the potential causes of accidents divided into environmental, technical and human factors. The latter comprise:

— Failure to comply with regulations (i.e. high speed);
— Failure to obtain ships position or course;
— Improper watchkeeping or lookout;
— Misconduct/Negligence;
— Drugs & Alcohol;
— *Fatigue*;
— Lack of knowledge;
— Error of judgement;
— Overloading;
— Physiological factors.

Fatigue, and impaired performance in general, is regarded as a significant factor in the majority of accidents occurring in transport systems (Fadda, 1984). In the maritime sector an analysis carried out in 1996 by the US Coast Guard (USCG) showed that out of 279 accidents, fatigue accounted for 16% of no-injury accidents and 33% of accidents involving injuries.

Background and fatigue studies. State of the art

It has been ascertained that fatigue, alertness, vigilance, stress and performance all have physiological roots. Two physiological factors, in particular sleep and circadian rhythms, are the primary determinants of arousal state.

Past research conducted on human fatigue prevention has focused on both the physiological mechanism and on methods for measuring fatigue levels (Sherry, 2000 & Czeisler, 1995 & Ji *et al.*, 2002). Current operator fatigue monitoring systems can be divided into two groups (Wylie *et al.*, 1996):

1) measurement of the extent and length of reduced alertness;
2) real time development of drowsiness control and alarm systems (Ji Q. & Yang X., 2002).

From a medical standpoint, research efforts are currently focused on investigating the complex process of fatigue and on the underlying internal and external factors and their interaction.

Lack of sleep leads to a deterioration in the main psychophysical functions which include cognitive processes, alertness, visual and physical coordination, judgement and decision making, communication, etc. Recently a cognitive definition of the factors causing workplace stress has been provided (Seck et al., 2005), distinguishing two macro areas, physical and mental, in turn divided into:

— physical: *environmental* (heat, cold, noise, vibrations, etc.) and *physiological* (lack of sleep, dehydration, muscle fatigue, etc.);

— mental: *cognitive* (too much or too little information, judgement difficulties, etc.) and *emotional* (pressure, frustration, boredom/inactivity etc.).

The same researchers carried out a study on human behaviour simulation using a dynamic stress model to obtain performance curves, adopting the model devised by Yerkes-Dodson (Fadda, 1984).

One of the main deliverables of these investigations are the arousal-performance curves, that provide an estimate of fatigue by measuring performance levels on the basis of task performed.

Numerous laboratory fatigue measurements have shown the process to be complex and no readily usable methods are available. The studies in question (Ji *et al.*, 2006) typically consisted in physiological, behavioural, facial behaviour and performance measurements.

Physiological measurements are used for evaluating fatigue and/or drowsiness, the most common being the electroencephalogram (EEG). Behavioural measurements, that have gained credibility recently, are used to gauge fatigue and are based on the frequency of body movements: the number of movements recorded during task performance over a specific time interval is significantly correlated with the EEG. Fatigue can also be readily detected by observing facial behaviour: changes of facial expression, eye and head movements, gaze are all indicators of fatigue. Others parameters such as eye pupil movement and saccades are indicative of the level of alertness. For example nominal gaze direction for a driver is forward: if gaze shifts in other directions for a prolonged period of time then this is indicative of fatigue and reduced alertness. The data obtained from these measurements, taken using medical instruments designed for diagnosis and not with research in mind, are not readily interpretable. Adopting the analytical methods typically used for dealing with complex data, such as neural networks (NN), Bayesian networks (BN) or fuzzy logic it is possible to treat and properly interpret incomplete, often partial information (Ji *et al.*, 2006).

Though numerous applications of electromedical devices for evaluating task performance in transport systems in general are reported in the international literature, the specific issue of crane operator fatigue has been little studied.

Italian researchers (Colombini, 2006) have conducted applied research in a number of human factor areas including anthropometry and ergonomics. Statistical tests, such as monitoring electromyographic activity using specialized instruments that record, display and amplify nerve response to local electric stimulation and determine muscle anomalies and disorders in specific work postures, have been performed to gauge physical performance of crane operators in non-operating conditions, for use by manufacturers to design innovative control stations for gantry cranes.

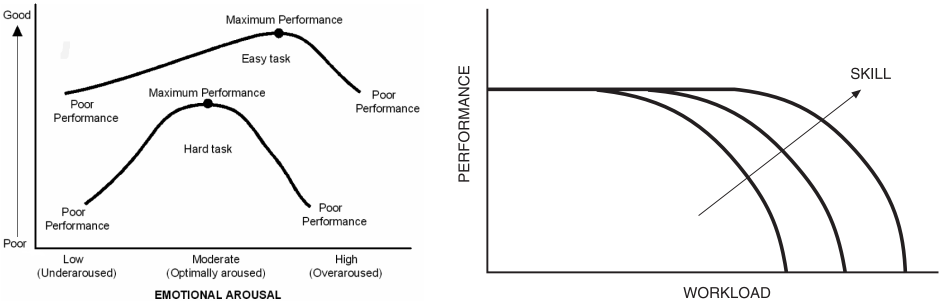
A training manual (Transportation Development Centre of Canada, 2002), provides guidelines for analysing fatigue, drowsiness and the resulting performance deterioration of Canadian navy personnel, combining EEG, EOG (eye movement), ECG (heartbeat) and EMG (muscle tone). It consists of two separate phases: determination of fatigue level and fatigue management programme (FMP). In the first phase drowsiness is determined as a measure of fatigue, associating eye movement and muscle tone with the specific electroencephalographic (EEG) patterns. Eye movements can be slow (SEM) or rapid (REM): during slow eye movements, for example when the examined subject is awake (eyes wide open), the EEG is characterized by closely-spaced irregular spectral fluctuations. Reduced alertness/vigilance is reflected by increased eye rotation and a reduction in EEG wave frequency, with the appearance of the so-called theta waves (the EEG pattern "slows down"). After a number of intermediate steps, the process terminates when the person falls asleep. The sleep stage may be Slow Wave Sleep (SWS), represented by large slow brain waves (delta waves) due to low brain activity or REM sleep during which muscle tone is reduced and EEG waves are sawtooth (apparently with a similar waveform to waking).

One particularly interesting area of human factors is the determination of the visual field using specific devices that identify and record operator gaze points during a work cycle. These applications (Camilli et al., 2007) aim to study the field of vision and the information required by the operator to cope with changing conditions, to determine whether any distractor signals exist that alter perception time and consequently the ability to make the right decision.

METHODS

The aim of this investigation was to construct experimental performance curves for container terminal ship-to-shore gantry crane operators, processed using the Yerkes-Dodson (Y-D) model shown in Fig. 1.

The Yerkes Dodson law states that there exists an inverted-U relationship between arousal and behavioural performance. The performance level is measured or plotted along the y-axis the emotional arousal (taskload) along the x-axis. Optimum



Figs. 1, 2. Yerkes-Dodson curves (complex and simple task) and theoretical relationship between performance, workload and skill.

arousal level and quality of performance will vary with task complexity. Initially, low workloads will result in poor performance, performance level then increasing in a directly proportional manner to arousal level until the optimum level has been attained. Viceversa, as workload increases so performance deteriorates, all the more so the more complex the task.

The upper curve which refers to an **easy task** is generally higher (high performance) and flatter, its peak is higher and lies to the right, while the lower curve for the **difficult task** is steeper and the peak is lower.

The two Y-D curves shown for the simple and complex tasks are both parabolic and can be described by the following 2nd degree equation (Eq. 1):

$$y = a \cdot x^2 + b \cdot x + c \qquad (1)$$

where

— the coefficient *a* determines the convexity (or shape of the parabola). As the Y-D curves are concave parabolas, **then we must have: "*a<0*"**;

— the coefficient *b* determines the position of the curve in the Cartesian plane chosen: varying the coefficient will shift the peak performance position (the time at which the peak number of containers are handled in the case at hand) with respect to the x-axis (arousal level), but also with respect to the y-axis. As the curves lie in the Cartesian plane representing the Y-D law (the x and y axes are both positive), **then we must have: "*b>0*"**;

— the coordinate of the intersection of the parabola with the y-axis will depend on the coefficient "*c*". If the curves are to lie within the quadrant of the Y-D function, we must have: "***c>0***";

— considering the two Y-D curves, the **curve for the simple task will have in** Eq. 1 **a lower value of *a* and higher values of *b* and *c* than the curve for the complex task;**

— the vertex of the parabola corresponds to peak performance (Eqs. 2-3). As this point lies in a Cartesian plane, then the vertices of the two curves are identified by a pair of (*x;y*) coordinates such that:

$$x = -{}^{b}\!/_{2 \cdot a} \qquad (2)$$

$$y = f \cdot (x) \qquad (3)$$

Some job tasks, for example gantry crane operation, require intense concentration and training. It has been observed that up to a certain point skilled operator performance may not diminish substantially, only to deteriorate irremediably thereafter

(Fadda, 1984). In this particular instance the resulting curve may be a combination of the two curves shown in Fig. 1, the first portion exhibiting the trend of the simple task, the second the trend of the complex task corresponding to a significant deterioration in operator performance (Fig. 2). As crane operators improve their skills, for example through training and refresher courses, the performance curve flattens out, the slope of the curve tail becoming increasingly gentler, similarly to the Y.D curve for the simple task, coming out of the "danger zone". Finally, by introducing training or refresher training, for example using a simulator, hard task curves tend to resemble more closely those for the easy task.

DEVELOPMENT

Application

The research work presented here was based an the analysis of data collected at Cagliari Port concerning the number of 20 ft/40 ft full or empty containers loaded/unloaded or restowed, or hatches opened/closed, every hour by a ship-to-shore crane operator[1]. Only those shifts during which the operator was engaged in handling activities for a full hour and not partial hours were considered, so as to obtain a more accurate measure of operator workload. It is important to note that operator idle times, due to unavailability of vehicles for loading/unloading or other work cycle coordination problems, can vary within the work shift from a few seconds to almost 30 minutes in one hour. These idle times can also be affected by psychophysical stress levels, operator experience and by weather conditions, so a certain degree of randomness for this variable clearly exists.

The workday in a container terminal consists of four 6 hour shifts (the last hour actually only lasts 45 minutes to enable shift handover, but the data have been made up to the hour to gauge workload more accurately):

- 1st shift (01:00 – 06:45)
- 2nd shift (07:00 – 12:45)
- 3rd shift (13:00 – 18:45)
- 4th shift (19:00 – 00:45)

[1] Containers are loaded/unloaded from ship to shore using spreaders, that are mechanically connected to the hoist motors via a beam suspended from cables and electrically connected to the crane. The container is hooked/unhooked by means of four corner flippers on the spreader. The containers are transferred from ship to shore through a combination of two movements: the spreader-container system is hoisted to the maximum clearance height, and the crane then travels with its load along the bridge rails to the buffer area. This operation is generally repeated at least 20 times an hour, the gantry crane continuously travelling back and forth between the ship and the yard.

Thus throughout the six hour shift the crane operator is exposed both to high vibration, due to cab movements, and to high noise levels generated by the very nature of the operation,. Added to this, is the discomfort caused by the bent forward posture and awkward head/neck positions that the operator is forced to assume to follow the movement of the container some 40 m below. These conditions create psychophysical stress that, over time, can lead to serious health problems and in terms of operational efficiency impair operator performance, to the detriment of container terminal productivity.

The numbers of containers handled were first treated for each hour of each shift for the entire period examined, so as to obtain a point analysis of operator performance, determining the maximum, minimum and average values and the delta (Δ=max-min).

Table 1 shows the values for each shift for the above parameters:

	Parameters	1st h	2nd h	3rd h	4th h	5th h	6th h
1st shift	*Max*	30	27	26	32	28	29
	Min	19	18	12	14	13	13
	Average	*24.6*	*22.5*	*21.6*	*21.1*	*21.1*	*20*
	Δ	11	9	14	17	15	16
2nd shift	*Max*	31	36	38	48	33	35
	Min	12	12	16	15	14	11
	Average	*21*	*23.7*	*23.2*	*22.5*	*22.5*	*22.7*
	Δ	19	24	22	33	19	24
3rd shift	*Max*	32	32	33	30	38	32
	Min	16	19	13	18	16	14
	Average	*22.6*	*24.1*	*24.7*	*22.8*	*24.1*	*22.4*
	Δ	16	13	20	12	22	18
4th shift	*Max*	40	32	33	31	29	27
	Min	15	18	14	16	18	8
	Average	*24.7*	*23.4*	*24.6*	*23.2*	*21.4*	*20.1*
	Δ	25	14	19	15	11	19

Table. 1. Parameters for the number of containers handled each hour for the four shifts

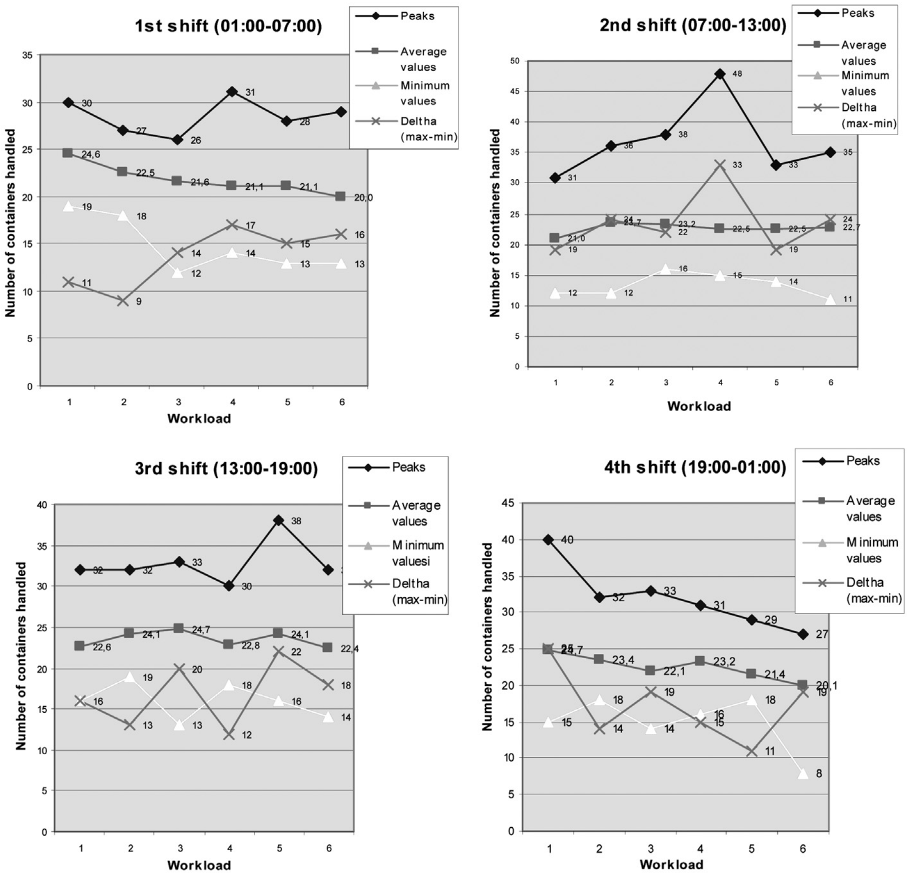
Figures 3-6 show graphically the distribution of the four parameters for each hour of the shift.

Results

The first important aspect is that the number of complete shifts on the 2nd shift was far higher than for the other three shifts. This indicates that planning of ship arrivals and a better overall organisation of the container terminal is concentrated between 07.00 and 13.00 hours, physiologically the most productive shift.

The absolute variability of each parameter was then analysed for each shift (Statistical Trial Absolute Variability – S.T.A.V.) in terms of percent increase and decrease of the maximum and minimum values for the first hour vis-à-vis those for last sixth as well as the percent variation of the average number of containers handled at the beginning and end of the shift (Statistical Trial Proportional Average Variability – S.T.P.A.V.):

— *1st shift*: absolute variability is –56.66% passing from a peak in the first hour (30 containers) to the lower value for the last hour (13 containers), while the



Figures 3,4,5,6: Performance parameter curves of (max, min, average, ?) crane operators at Cagliari port (September 2007).

variation in the average value between the beginning and end of the shift is –18.69%;

— *2nd shift*: absolute variability is + 191.66% (from a minimum of 12 for the first hour up to a maximum of 35 in the last), while variation in the average number of containers handled is + 8%;

— *3rd shift*: absolute variability is –56.25% (peak in the first hour of 32 lowest value of 14 at the sixth); variation in the average number is –0.9%;

— *4th shift*: lastly, absolute variability for the night shift is –80% (from 40 at the beginning of the shift to 8 at the end), while variation in the average number –18.62%.

The most salient aspects of the analysis can be summarised as follows:

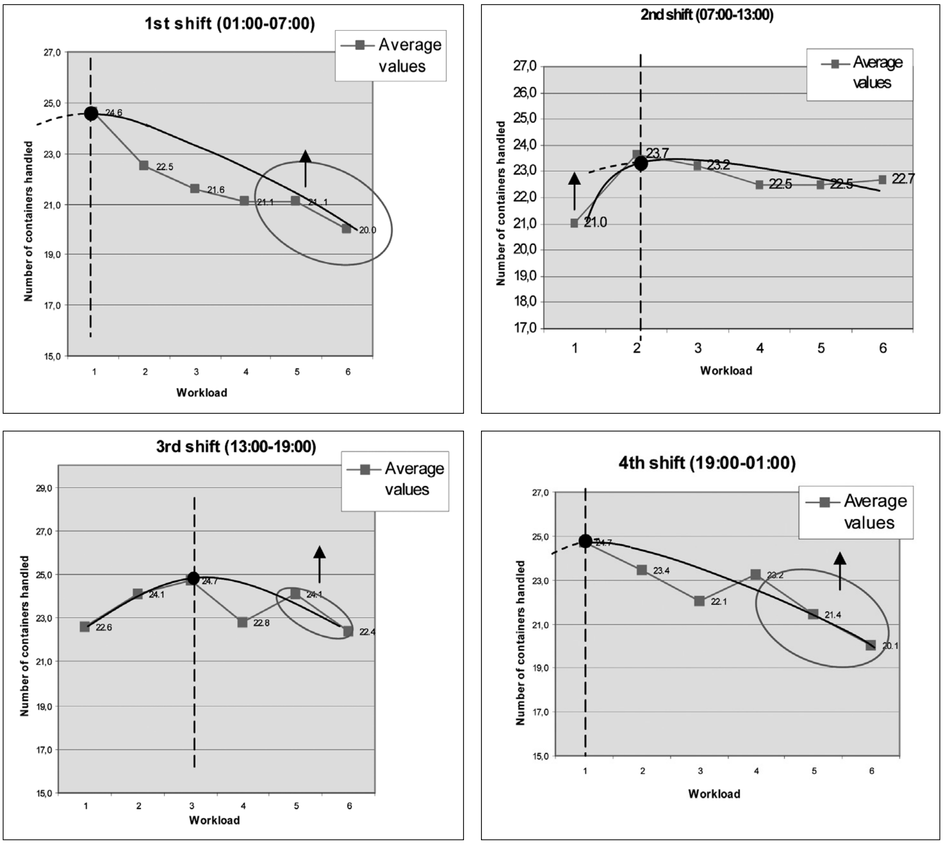
— a significant decline in crane operator performance was observed during the 1st and 4th shifts, only a minor deterioration in the 3rd, while performance levels increase in the 2nd shift. This implies that operators become more fatigued during the night shift, unlike during the day shift, when operator performance actually improves as the day goes on;
— the 2nd shift was the most productive as the operator has been able to sleep adequately prior to starting work, performance peaking between the 2nd and 3rd hours of the shift. Note that the minimum and maximum curves in Figures 4-7 are practically constant (except for the 48 containers handled in the fourth hour), and fairly flat, closely resembling the Y-D curve for simple tasks. The shape of the curve for the 3rd shift indicates on average only minor operator fatigue, most likely explained by the time of day. In fact the operator starts his shift having already absorbed half a day's mental and physical workload, which probably explains the sharp decline in performance after the fourth hour;
— restricting the analysis to a single hour, in the 1st and 4th shifts the peaks for number of containers handled during the first hour are higher than for the 2nd and 3rd shifts. A likely explanation is that the operator is psychologically conditioned to performing well at the beginning of the shift, knowing he has to work through the night. From the second hour onwards this condition is no longer perceived;
— again restricting the analysis to one hour, a clear phenomenon can be observed in the Δ curve for the 1st shift. In fact, the values are lower for the first two hours, increasing from the third hour onwards. This indicates that the number of containers handled early on in the 1st shift is fairly similar, whereas later on in the shift, probably due to fatigue, the values are very high or very low, which may well correspond to operator experience or inexperience respectively.

One last remark on the relationship between shift (biological clock) and performance of ship to shore crane operators: in the first part of the 2nd shift (between the first and second hour) performance increases by 12.85 % (from 21 a 23.7), almost twice as much as the 6.63 % in the 3rd shift for the same time (from 22.6 to 24.1). This can be explained by the fact that at that time in the morning the operator is more physically and mentally alert and certainly concentrates better than during the rest of the day.

Figures 7-10 show average number of containers handled for the four shifts and the corresponding interpolated curves which exhibit a parabolic trend in accordance with the Yerkes-Dodson law described above. The performance curves for the 1st and 4th shift are described by the right branch of the parabola, with peaks of 24.6

and 24.7 respectively. Note that the maximum values are attained at the beginning of the curve (1st hour), decreasing throughout the rest of the shift. The performance curve for the 2nd shift is an asymmetric parabola, consisting of two parabolic branches[2], and hence two different functions, having the same vertex. After an initial sharp increase in performance, the curve stabilizes, becoming constant. The trend of the curve for the 3rd shift is the only typical symmetric parabola with respect to the x-axis (peak in the 3rd hour).

In light of the above, the decreasing tail at the third hour (circled in red) for the 1st, 3rd and 4th shifts, corresponding to the “danger zone” of the Y-D” curve of Fig. 2, can be clearly seen.



Figs. 7,8,9,10. Average performance curves for the 4 shifts and corresponding parabolic trend.

2. Note that for the sake of simplicity the curve for the 2nd shift consists of two different parabola equations, but in actual fact this would have required a function study on a single trend of the curve.

Examining the equations for each parabola, the following values were obtained for the characterizing parameters (Table. 2):

	Peak (x;y)	Coefficients		
		a	b	c
1st shift	1 ; 24.6	-0.045	0.60	24.6
2nd shift (left branch)	2 ; 23.7	-0.200	0.75	17.9
2nd shift (right branch)	2 ; 23.7	-0.005	0.75	22.0
3rd shift	3 ; 24.7	-0.456	2.85	20.2
4th shift	1 ; 24.7	-0.048	0.58	24.7

Tab. 2. Parametrization of interpolation parabolas for average number of containers handled

As can be seen, performance curves for the 1st and 4th shifts are practically the same, exhibiting at the beginning the decreasing tail of the Y-D curve for complex tasks. The shape and trend of the symmetric parabola for the 3rd shift can also be typically associated with the Y-D curve, whereas the first portion of the symmetric parabola for the 2nd shift consists of a parabola branch having the characteristics of the Y-D curve for complex tasks, followed by parabola branch similar to the Y-D curve for simple tasks, from the second hour up to the end of the shift.

From the applications, indications of a general nature can be drawn for the curve structure in relation to the type of task performed. Experimental data can be used to indicatively determine the range within which the parameters (curve peak and coefficients) of crane operator performance curves lie for simple and complex tasks. (Table 3):

	Peak (x;y)	a	b	c
Easy Task Curve	$3 \leq x: \leq 6;\ y \geq 22$	0 ÷ -0.20	+3 ÷ +6	+22 ÷ +25
Hard Task Curve	$1 \leq x: <3;\ y <22$	-0.20 ÷ -1	0 ÷ +3	+10 ÷ +22

Table 3. Indicative parametrization of Y-D parabolas for crane operator

New research prospects on ship-to-shore gantry crane operator performance

The curves described above refer to average crane operator performance determined using operational data. To determine the effects on human operators of all the variables contributing to fatigue as well as psycho-physical stress using the electromedical devices described, operator tasks need to be experimentally reproduced in the laboratory, so as to provide a more realistic and reliable measure. Similarly to the simulators long employed in the aviation and aerospace sectors, gantry crane simulators are now being introduced into ports not only for training but also for research purposes.

In the maritime transport sector simulators are utilised mainly for accelerated and cost-effective operator training as well as for refresher training, to keep operators abreast of the continuous technological changes in equipment, resulting in a strong demand for highly skilled personnel. Refresher training is also important for keeping potential performance levels high in specific operating conditions that may on the one hand be detrimental to terminal productivity and on the other create a serious risk of accident.

In the case at hand, the use of the simulator allows to attenuate the decline in those parabola branches corresponding to the crucial phases of the gantry crane operator's work shift described above (arrows in graphs of Figs. 7-10).

In research applications the simulator is widely used for optimising the man-machine interface and for fatigue analysis, in an attempt to establish why humans make errors. It is also an effective instrument for transport systems design and for operator training and for this reason is widely utilised in the container handling sector, because of the need for terminals to achieve increasingly higher levels of efficiency (Rocca et al., 2007).

Simulators also prove useful for quantifying operator workload (over- or under-work). Establishing workloads involves a variety of aspects from definition of operating cycles, to determining the number and type of personnel required, to training as an integral part of the company's business and for achieving safety. Equally important is the design of suitable devices for assisting the operator in his task and consequently of minimizing performance deterioration.

In this regard a project is now under way, that for the reasons described above falls into the area of active safety and aspects concerned with human factors in container terminals, for setting up a network of simulators to be located in different areas in central-southern Italy (*cyberinfrastructure*), that will enable integrated task training, by distance testing and tests coordinated by an efficient multimedia network.

The CIREM research centre at Cagliari University, in collaboration with the Consorzio COSMOLAB, is currently constructing a **gantry crane simulator** (Fig. 11). Once completed and tested, the simulator will be used for the following activities:

— training and refresher training at port and interport terminals or directly at advanced professional training organizations;
— human performance research vis-à-vis different operating conditions using objective medical parameters;
— studying and validating new design options for crane control systems.

The project aims to quantify and evaluate the level of performance and fatigue of gantry crane operators devising research plans, currently being perfected, using advanced tools for the virtual reality simulation of crane operator tasks.

Because of the difficulties in obtaining accurate and reliable measurements of these parameters inside the gantry crane cab while the operator is actually working (confined spaces, difficulties in locating the instruments , conflicts with terminal operability, etc), also due to the numerous disturbance interactions, the gantry crane

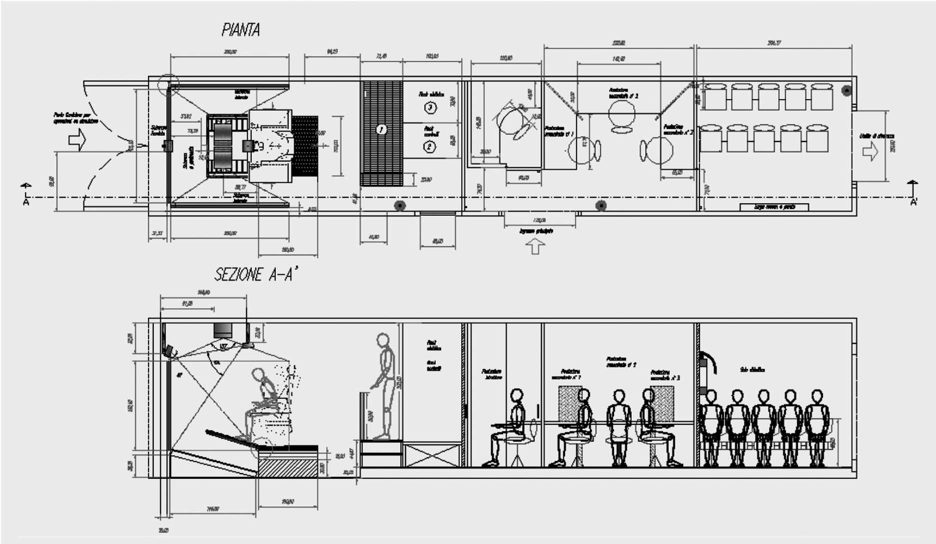


Fig. 11. Plan and cross-section of Cagliari University's containerized gantry crane simulator.

simulator will be built as a permanent laboratory for monitoring fatigue by measuring parameters such as EOG (electrooculograph), ECG, EEG, arterial blood pressure, S.N.C., flicker fusion point, heartbeat, which provide a measure of the operator's psychophysical conditions under different workloads (Rocca et al., 2007).

A simulator is a useful tool for obtaining objective undisturbed measurements of the workload (over-or underwork) and of any psychophysical stress caused by task complexity, as well as of exposure to strain and vibrations and external stimuli (reproduced in the virtual environment) associated with the onset of fatigue (Fadda, 1984).

CONCLUSIONS

The research activity described here has enabled, for the first time in the scientific panorama, to construct performance curves for each work shift of a gantry crane operator.

Analysis of these curves showed operator performance to deteriorate significantly during the early and late shifts, performance levels dropping into the downward branch of the curve considered at risk.

The ultimate objective is to reverse this downward trend, attenuating the deterioration in performance. This can also be achieved utilizing a gantry crane simulator. Thus the next step will be to evaluate the effectiveness of simulator training activities, and explore whether the performance curves can be improved after adequate training and refreshers.

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ELABORACIÓN Y ANÁLISIS DE LAS CURVAS DE PRESTACIONES DE LOS OPERADORES DE GRÚA DE MUELLE EN LAS TERMINALES DE CONTENEDORES MARÍTIMOS

Resumen

Hace tiempo que, para representar el nivel de prestaciones de un operador especializado en el sector de los transportes, se utilizan curvas que relacionan la calidad de las prestaciones con el nivel del estímulo al que es sometido el operador. Esto sucede, desde hace más de 30 años, en el sector aeronáutico, y desde antes aún en el aeroespacial.

Con el desarrollo de la tecnología y la introducción de tareas con elevado grado de especialización, también en el sector portuario ha surgido la exigencia de poder contar con instrumentos analíticos de este tipo, que favorecieran la calidad de las prestaciones de los operadores limitando el grado de fatiga, y por lo tanto la eventualidad de sucesos lesivos.

En el presente artículo se quieren representar analíticamente las curvas de prestaciones de un operador de grúa de muelle de un terminal portuario de transhipment: tales curvas son relativas a los 4 turnos de la jornada laboral y permiten verificar las fases temporales más críticas de su tarea en función de la actividad desarrollada. Los resultados del análisis evidencian cómo la determinación de las curvas para tipologías de tarea específicas debe realizarse con el empleo del simulador, capaz de representar todas las condiciones operativas, incluso las más atípicas y menos frecuentes.

DESARROLLO METODOLÓGICO

La seguridad de los sistemas de transporte, en particular en el sector marítimo, depende sustancialmente del error humano. Las actividades en ámbito portuario están caracterizadas por el alto porcentaje (entre el 80% y el 90%) de sucesos lesivos cuya causa o concausa es el error humano. La fatiga, y en general el decaimiento del nivel de prestaciones, es considerada un factor significativo en la mayor parte de los accidentes en los sistemas de transporte. La medida de la fatiga ha sido llevada a cabo en numerosos estudios de laboratorio, que han demostrado lo complejo de este proceso y el hecho de que no existen métodos disponibles de fácil empleo. Uno de los principales resultados de la investigación es la curva estímulo-prestación, que evalúa la fatiga a través de la medida del nivel de prestaciones según el tipo de tarea efectuada. Curvas de prestaciones típicas son las representadas según el modelo de la función de Yerkes Dodson.

Una tarea en el ámbito marítimo que responde a las características tanto de alto nivel de especialización, como de grado de fatiga, es la del operador de grúa de muelle de un terminal portuario: las exigencias del puesto, y la posición de trabajo anómala que el operador gruista sufre por toda la duración de su turno laboral (seis horas), ocasionan fuertes condiciones de estrés psicofísico que, desde el punto de vista sanitario, pueden conducir con el tiempo a patologías en ocasiones relevantes, mientras que desde el punto de vista operativo determinan una reducción de las prestaciones y por lo tanto un menor nivel de productividad del terminal.

El estudio de la fatiga de un operador de grúa portainer no tiene mucho eco en la reciente literatura internacional: numerosas aplicaciones, en cambio, se han referido al empleo de los instrumentos electromédicos para la valoración de prestaciones de una tarea dentro del campo más general de los sistemas de transporte.

En este artículo, el objetivo ha sido elaborar las curvas experimentales de prestaciones relativas a operadores de grúa de muelle de un terminal de contenedores elaborado según el modelo de la función de Yerkes-Dodson (Y-D).

La investigación ha permitido dibujar tales curvas, basadas en el aporte de prestaciones de los operadores de grúa de muelle del Puerto de Cagliari (Cerdeña, Italia), obtenido de un banco de datos mensual correspondiente al período de septiembre de 2007, sobre el movimiento de contenedores de los 4 turnos laborales, y reproducido por el terminal en los informes de prestaciones de fin de turno, en los que se transcribe el número de movimientos por cada gruista de muelle y por cada hora.

El artículo contiene el análisis de la evolución de las curvas, además de las ecuaciones de las curvas de interpolación parabólica relativas a los 4 turnos de la jornada laboral; de tal modo ha sido posible obtener los primeros elementos significativos sobre las prestaciones del gruista de muelle: esquemáticamente, se ha efectuado un análisis estadístico de las curvas y, analizando las ecuaciones de las parábolas específicas, se han obtenido los valores relativos a los parámetros que las caracterizan; así se han podido verificar las fases temporales más críticas de su tarea, en las que intervenir con el empleo del simulador de grúa portainer, y de los datos experimentales de las aplicaciones se han podido extraer indicaciones de tipo general sobre la estructura de las curvas según la tipología de tarea.

Las curvas obtenidas eran relativas a valores medios de las prestaciones del gruista medidos por los datos de operatividad, pero para evaluar los efectos sobre el hombre de todas las variables que influyen en el cansancio, y para poder medir con los aparatos electromédicos el estrés psicofísico en el hombre, es necesario reproducir tal tarea al laboratorio, garantizando la reproducibilidad de la misma lo más fiable y realista posible.

El CIREM de la Universidad de Cagliari, en colaboración con el Consorcio COSMOLAB, está completando la realización de un simulador físico de grúa portainer, que verá su empleo en el campo de la formación y los cursillos formativos, en el estudio del nivel de prestaciones del hombre respecto a las diversas modalidades operativas a través del empleo de parámetros objetivos de tipo médico (EEG, ECG, EOG, EMG, *Holter Monitoring,* etc.), y en la actividad de investigación y validación de nuevas soluciones proyectivas para los sistemas de control y mando de la grúa.

La acción formativa está enfocada a proveer altos niveles de especialización y calidad de las prestaciones, para mejorar por un lado la seguridad y, por el otro, la productividad del sistema.

El objetivo del proyecto de investigación, en cambio, para aportar al simulador, instrumento de apoyo típico de la disciplina de los *human factors*, será definir, cuantificar y valorar determinísticamente el nivel de prestaciones y cansancio del operador de grúa portainer, desarrollando programas de investigación, al momento en fase de perfeccionamiento, mediante el uso de instrumentos de elevada capacidad para la simulación virtual de las tareas.

De tal modo se podrá confrontar el perfil de las curvas experimentales de prestaciones, presentadas en este artículo, con las objetivas, realizadas en el simulador utilizando los instrumentos electromédicos. Se podrá valorar además la eficacia de la acción formativa del simulador, verificando la evolución de las curvas de prestaciones de los operadores, tanto en formación como ya formados, en correspondencia con las zonas críticas para la seguridad y la productividad del terminal.

CONCLUSIONES

La presente actividad de investigación ha permitido elaborar, por primera vez en el panorama científico, las curvas de rendimiento de un operador gruista por cada turno al que es sometido.

Los análisis han evidenciado que, en los dos turnos extremos de la jornada (1° y 4°), las prestaciones decaen repentinamente, situándose en el tramo descendiente de la curva considerado «de alarma».

El objetivo primario es transformar las inclinaciones de la curva, atenuando la caída de la misma. El empleo del simulador de grúa portainer puede contribuir al logro de tal resultado.

Por tanto, la siguiente fase de investigación será la evaluación de la eficacia de la acción formativa del simulador, verificando la posibilidad de poder corregir las curvas de prestaciones, después de adecuadas aplicaciones de cursillos formativos.