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Development of a weight-based technique for 'packages labelled by count' of agricultural products

AVITAL BECHAR[1] and GAD VITNER[2]

ABSTRACT

Accurate weight-based packing of 'packages labelled by count' necessitate very low coefficients of variation of unit weight. For agricultural products with relatively high coefficient of variation, the usual weighing methods are therefore not suitable. In this paper, a method that supports the count-to-weight transform of pre-packed packages of products with wide variability of characteristics is presented. The developed innovative weighing method utilises a weighing procedure where the coefficient of variation of the product's unit weight is used in order to determine the critical package weight and to comply with the package nominal definitions. The method involves a weighing procedure of 'packages labelled by count' which is based on a mathematical model which reduces the variability in package size and eliminates the cases of under filling of packages.

The method was validated experimentally. The results revealed that the variability of package size is high when counting manually. In contrast, by implementing the proposed method the standard deviation of the quantity in a package was reduced by 30%. Moreover, the number of packages with quantity less than the nominal was reduced to zero. In general, the developed method can be applied when the coefficients variation is high and the counting procedure is inaccurate and/or expensive.

KEYWORDS: Decision analysis; coefficient of variation; weighing procedures; cuttings

1. Introduction

The actual quantity of product units in pre-packed packages is an issue that concerns both the consumers and the producers. The consumers have the right to expect packages to bear accurate net content information, while on the other hand, the producers aim to pack the specified nominal quantities at a minimum cost. Routine verification of the net contents of packages is an important part of any weights and measures program intended to facilitate value comparison and fair competition.

There are several methods to quantify the contents of pre-packed packages: counting, weighing, or volume measurement. Every manufacturer aims to pack the specified nominal quantities into a package, at minimum cost. In various industries (food, agriculture, plastics, machined products, wood, pharmaceuticals, etc.) there is a need to create packages with a nominal content defined by a specified numerical quantity. Some products, e.g., screws, may be packed by automatic means, mainly due to very small weight variability, while others, must be packed manually, either because their wide variability of characteristics and complex handling prevents any economic justification for an automated solution, or because there is no feasible automated solution available.

When the product quantities involved in each package unit are large, two problematic issues need to be addressed:

i) The manufacturer tends to design a packaging strategy which ensures that the nominal quantity is achieved. This is usually done by adding a fixed percentage, e.g., 10%, of the nominal quantity to each package;
ii) There is a problem with the employee performing the counting task. This is a very monotonous and tedious job, which encourages the employee to apply large personal safety margins.

The outcome of both these issues is packages that contain more than the nominal quantity (overfilling).

The literature dedicated to packaging methods for agricultural products is limited. Most of the studies deal with the quality aspects of the products, packaging materials, traceability and packages atmosphere rather than the methods used to fill the packages. Anthony (2001) developed a system to reduce the packages forces of cotton bales up to 35%. In examination of flower cutting packages Vitner *et al.* (2006) reported on a significant variability of the number of cuttings per package with the mean close to 20% above the nominal level, resulting in excessive overfilling. They proposed a method resulting in a significant reduction in overfilled packages which translates to increase in revenue. Li *et al.* (2005) developed an automatic packaging system for automatic packaging of milk standards with filling

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[1] Corresponding author: Institute of Agricultural Engineering, VolcaniCenter, Israel; avital@volcani.agri.gov.il
[2] School of Engineering, Ruppin Academic Center, Israel.

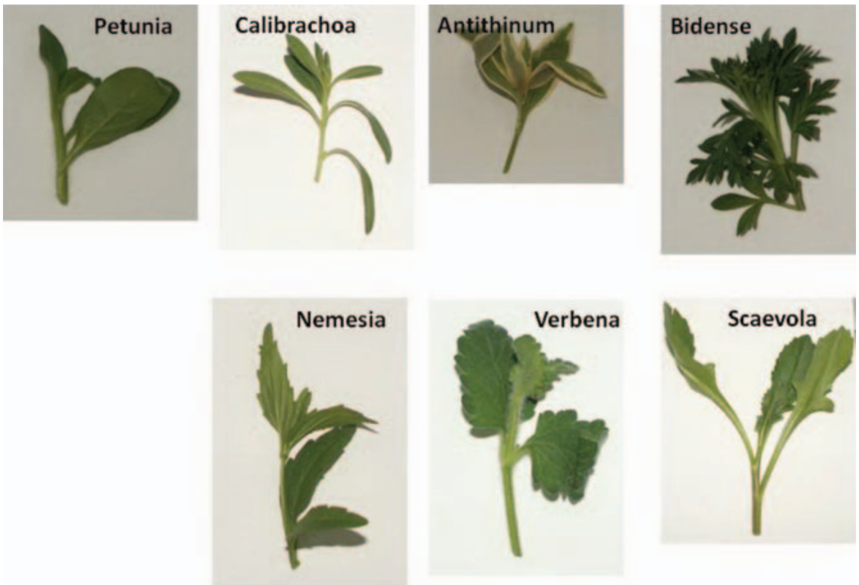


Figure 1: Typical ornamental plant cuttings

accuracy of 40. ± 1 ml, meeting the industrial standards and a capacity of 30 to 40 vials per min. In the developed automatic packaging system, the capping, filling, and label printing operations were automated through a programmable logic controller (PLC). A wheat flour milling traceability system (WFMTS), incorporating 2D barcode and radio frequency identification (RFID) technologies was developed by Qian *et al*. (2012). The system increased the total operational cost by 17.2% and the sales income by 32.5%.

A useful statistic value for comparing the variability of variables with different means and different standard deviations is the coefficient variation (CV) which is defined as the measure σ/μ, where (σ) is the standard deviation and (μ) is the mean. Different products have different CV values. In packaging of plant cuttings, Vitner *et al*. (2006) found that the CV ranged from 0.17 to 0.23. Bechar *et al*. (2001) investigated injuries to apples during harvest and transportation, and found that the CV was 0.17. Zion and Lev (1996) investigated a weighing method as an alternative procedure for sorting Aster, Hipericum, Solidaster, and Solidago cuttings, and reported that their CVs were ranged from 0.22 to 0.54. Cronin *et al*. (2003), investigated the weight variability in extruded food products and found that the CV was ranged from 0.047 to 0.096. Hauhouot-O'Hara *et al*. (2000) calculated the CV of the length, width, and thickness of seeds in the process of selecting the size and shape of holes in screens used to separate chaff from wheat. Morales-Sillero *et al*. (2008) used CV as an aid in verifying the influence of nutrient supply on olive dimensions (weight, length, and equatorial diameter). Hoffmann *et al*. (2007) used CV measurement to determine the distribution of foreign material inside the box during potato harvesting.

This study aims to develop a weight-based method for 'packages labelled by count' of agricultural products which minimises the difference between the actual number of units in a package and the nominal number. A mathematical weight CV-based model was developed to support the production of packages of cuttings that were 'labelled by count'. The model determines the critical package weight, which is the most compatible with the package characteristics according to the specific product's CV.

2. Material and Methods

Count-to-Weight Transform Methodology

In order to utilize the transform methodology, it is assumed that the package weight, w, is distributed normally (i.e., the package weights are normally distributed, under the assumption that the number of individual items in each pack is large, usually above 30) based on the Central Limit Theorem:

$$w = N \sim \left(n \cdot \mu, \sqrt{n} \cdot \sigma\right) \tag{1}$$

where μ is the average weight of one product unit and n is the nominal number of product units in a package.

Five basic packaging characteristics were defined:

$\bar{n}$ – the mean number of items in a package;

n_L – the minimum number of items in a package;

n_U – the maximum number of items in a package;

Δn – the range of numbers of items in a package, $\Delta n = n_U - n_L$; and

CR_n – the ratio between Δn and $\bar{n}$ (Bechar and Vitner, 2009).

Figure 2: Lavateramaritima(left) and Picking Lavateramaritima cuttings (right)

Table 1: Descriptive statistics for the different cutting varieties. The data represents statistics on weights of a single cutting

Species	Mean [g]	SD. [g]	No. of samples	Min [g]	Max [g]	CV
Bidens	0.17	0.05	102	0.08	0.31	0.28
Candy snap	0.20	0.04	110	0.13	0.32	0.20
Calibrachoa	0.10	0.02	114	0.06	0.15	0.19
Petunia	0.30	0.08	104	0.11	0.56	0.27
Scaevola	0.61	0.24	105	0.25	1.44	0.39
Verbena	0.14	0.03	106	0.08	0.24	0.24
Nemesia sp.	0.12	0.04	95	0.05	0.24	0.32

Any farmer aims to deliver to the market packages that comply with the specified nominal number of units, and she/he may adopt various strategies, depending on market or customer demands, such as the minimum quantity package strategy in which the number of units in a package (n_L) should not be less than $n-\delta$, where δ is an integer number in the range of $n+1>\delta>-\infty$. The basic characteristics of the package can be calculated according to the product CV and the farmer's strategy.

The weight distribution of the cuttings creates a package weight range and for a given population of packages with mean weight W_μ, the maximum and minimum number of items in a package is n_U and n_L, respectively.

The critical package weight is the minimum allowable weight of a package enabling the worker to decide whether a package complies with the requirements; it is calculated according to the basic characteristics of the package, the average weight, and standard deviation of the product:

$$W_\mu = n_U \cdot \mu - 3\sqrt{n_U} \cdot \sigma \qquad (2)$$

The critical weight, W_μ, assures that the maximum number of cuttings in a package will not exceed n_U. The maximum and minimum number of items in a package and the range of numbers of items in a package can be expressed in terms of the coefficient of variation, CV, and the nominal number of items in a package Bechar and Vitner (2009):

$$n_U = \frac{9}{2}CV^2 + n + 3CV \cdot \sqrt{\frac{9}{4}CV^2 + n} \qquad (3)$$

$$n_L = \frac{9}{2}CV^2 + n - 3CV \cdot \sqrt{\frac{9}{4}CV^2 + n} \qquad (4)$$

$$\Delta n = 6CV \cdot \sqrt{\frac{9}{4}CV^2 + n} \qquad (5)$$

As for example, in the case of Candy Snap, the mean weight of a single plant cutting is μ=0.20 g and the standard deviation is σ=0.04 g. The mean weight of a package, W_μ, with nominal number of 200 plant cuttings is 40 g. The number of cuttings in such a package will range between 193 (n_L) and 209 (n_U). If the requirement is that the number of cuttings in a package should not be below 200, then the average package weight will be 41.7 g. The mean number of cuttings in a package will be $\bar{n}$=208.5 and the maximum number of cuttings in a package will be n_U=218 cuttings. A similar detailed analysis was presented by Bechar and Vitner (2009).

Weighing Procedure

In order to examine the characteristics of different cuttings, and verify the equations, cuttings of seven ornamental plant varieties were weighed with an MP-3000 digital scale (Chyo Balance Corp., Tokyo, Japan). The varieties were: Bidens, Antithinum Candy Snap, Calibrachoa Celebration Dark Blue, Petunia Surfinia, ScaevolaSaphira, Verbena Temari and Nemesia sp. (Fig. 1). Typical dimensions of the cuttings were 25 mm to 70 mm for the width and 40 mm to 85 mm for the length. Each cutting was weighed and the number of cuttings for each variety was counted. For each variety the mean weight, the standard deviation and the CV, were calculated.

Validation

An experiment was conducted to examine the developed method. The experiment was executed in a cutting nursery located at central part of Israel (Fig. 2, right). The examined cutting was *Lavateramaritima* (Fig. 2, left). Since cuttings are seasonal crops, in the time of the experiment the cuttings described in the previous section were not available in the nursery that the experiment was performed. In the experiment, two methods were examined:

i) the current method - the workers picked cuttings and put them in a package (a plastic bag). The workers counted the number of cutting during their work. When the number of cuttings reaches the required figure, the bag is closed and the worker continued with a new bag.

ii) The modified method - the worker picked cuttings without counting into a container, after picking a certain amount, the minimum allowed weight of a package was calculated and

Table 2: Package characteristics of *Nemesia sp.* for various values of $\bar{n}$

$\bar{n}$	10	20	50	100	200	500	1,000	5,000	10,000
W_μ	1.20	2.40	5.99	11.98	23.96	59.89	119.8	598.9	1197.8
n_L	7.38	16.12	43.62	90.79	186.8	478.8	969.9	4932	9904
n_U	13.56	24.81	57.32	110.1	214.1	522.1	1031	5069	10098
Δn	6.18	8.69	13.70	19.35	27.35	43.23	61.13	136.7	193.3
CR_n	0.618	0.435	0.274	0.193	0.137	0.0865	0.0611	0.0273	0.0193

Table 3: The product regression equation coefficients

variety (i)	CV	n_U		n_L		Δn		CR_n	
Eq. coeff.		a_0	a_1	a_0	a_1	a_0	a_1	a_0	a_1
Bidens	0.285	1.2368	0.9794	0.8085	1.0206	1.7185	0.4994	1.7185	−0.5006
Candy snap	0.196	1.1573	0.9859	0.8641	1.0141	1.1769	0.4997	1.1769	−0.5003
Calibrachoa	0.193	1.1553	0.986	0.8656	1.014	1.1626	0.4997	1.1626	−0.5004
Petunia	0.270	1.2228	0.9805	0.8178	1.0195	1.625	0.4995	1.625	−0.5005
Scaevola	0.392	1.3391	0.9718	0.7468	1.0282	2.3752	0.499	2.3752	−0.501
Verbena	0.236	1.1926	0.983	0.8385	1.017	1.421	0.4996	1.421	−0.5004
Nemesia sp.	0.322	1.2715	0.9768	0.7865	1.0232	1.9459	0.4993	1.9459	−0.5007

then cuttings were loaded on a scale. When the scale reaches the minimum allowed weight, the worker inserts the cuttings into the package. In each method, 20 packages were filled and packed. The nominal number of cuttings per package for both methods was 50. However, in the current method, the farmer packaging strategy was to pack 54 cuttings in each package in order to ensure that the nominal quantity is reached. In both methods, after the packaging stage was completed all packages were opened and the number of cuttings in each package was accurately counted. In addition, above 150 cuttings in each method were weighted separately in order to evaluate the cuttings population characteristics.

3. Results

Cuttings weight characteristics

A total of 736 cuttings from seven varieties were weighed. The values of CV for the various varieties ranged from 0.19 for *Calibrachoasp.* to 0.39 for *Scaveolasp*. The results shown that varieties with similar average weights, i.e., *Calibrachoa sp., Verbana sp.* and *Nemesiasp.*, had differing CV values that derived from the natural characteristics of each product. Thus, for two varieties with the same average weight, different critical weights will be determined. Table 1 presents descriptive statistics for all varieties.

Count-to-Weight Transform Methodology

Package characteristics analyses were conducted for all cutting varieties. At first, the required package characteristics were determined, the variety CV was taken from Table 1, and then the critical package weight, W_μ, and the remaining package characteristics were calculated. Table 2 listed the critical weights, W_μ, and the package characteristics, calculated for *Nemesia sp.* and different ñ. For each package characteristic and each variety, a polynomial regression equation was found. A general form of the equation is:

$$f_{ij}(x_i) = a_{0ij} \cdot x_i^{a_{1ij}} \qquad (6)$$

where index i represents the product type (i.e., variety in our case), index j represents the calculated package

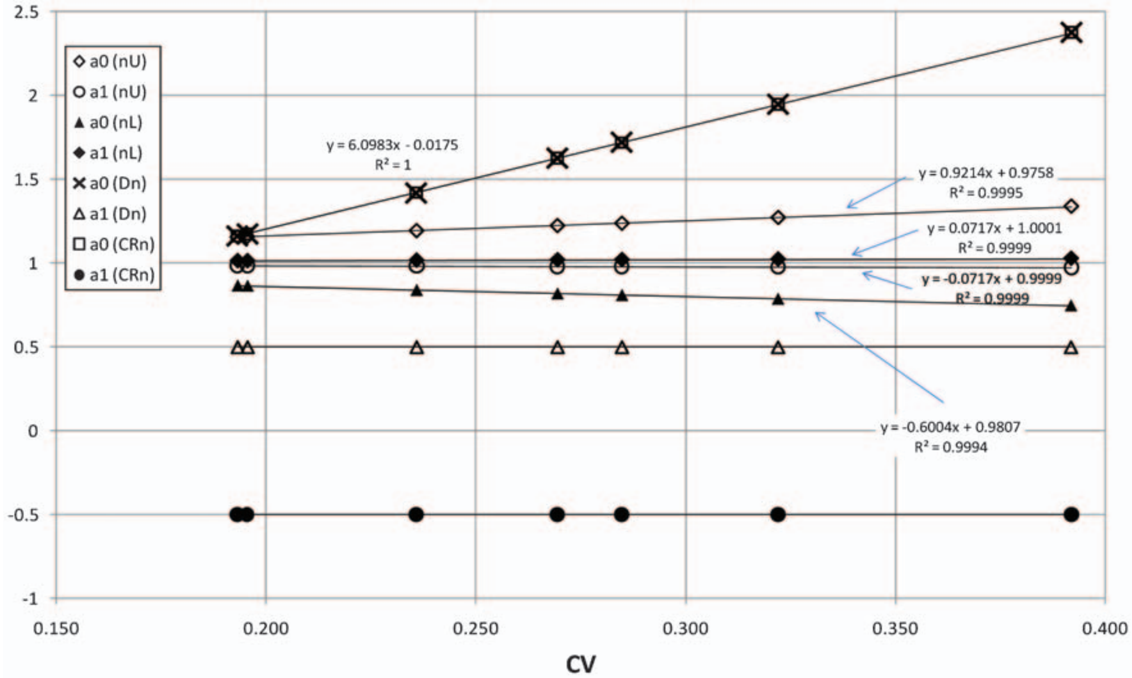


Figure 3: Calculated strategy regression equation coefficients and the correlation coefficients for all package characteristics in the minimum package strategy

Table 4: The strategy regression equation coefficients for the minimum package strategy

	$\bar{n}$		n_L		n_U		Δn		CR_n	
	α_o	α_1	α_o	α_1	α_o	α_1	α_o	α_1	α_o	α_1
a_0	-	-	−0.600	0.981	0.921	0.976	6.098	−0.017	6.098	−0.017
a_1	-	-	0.071	1.000	−0.071	1.000	0	0.500	0	−0.500

characteristics, x represents the predetermined package characteristic (e.g., $\bar{n}$), f is the calculated package characteristics and, a_o and a_1 are the equation coefficients. This equation is designated as the 'product regression equation' because its coefficients are dependent on the specific product CV. The coefficient of determination, R^2, was higher than 0.9997 for all varieties.

The polynomial regression equation coefficients, a_o and a_1, of each package characteristics are given in Table 3.

The results indicate that the values of a_o, CR_n, and Δn are equal and the value of a_1 is opposite for CR_n and Δn. Since CR_n equals Δn divided by $\bar{n}$, and in the minimum package strategy, $\bar{n}$ equals n, for high $\bar{n}$ (i.e., above 100), Eq. 5 could be simplified to $\Delta n \approx 6CV \cdot \sqrt{n}$, therefore:

$$CR_n \approx 6CV \cdot \frac{1}{\sqrt{n}} \tag{7}$$

The relationships between the value of CV and the coefficients a_o and a_1 were investigated. For each package characteristic, a linear regression equation was determined:

$$a_{k,j}(CV) = \alpha_{0kj} \cdot CV + \alpha_{1kj} \tag{8}$$

where index k can be 0 or 1, to designate the coefficient a_o or a_1, respectively, index j indicates the calculated package characteristics. This equation is referred to as the 'strategy regression equation' since the equation coefficients α_o and α_1 for each package characteristic depend only on the strategy. For all strategy regression equation, R^2 was higher than 0.9995.

Figure 3 shows the effect of CV on the product regression equation coefficients of the various package characteristics and on the calculated strategy regression equation coefficients and their correlation coefficients in the minimum package strategy. Table 4 shows the polynomial regression equation coefficients, a_o and a_1, of each package characteristics found for the minimum package strategy.

In practice, when applying the present model, the farmer needs to have the product CV in order to determine the critical package weight and to comply with the package definitions.

Nursery Experiment

The descriptive statistics on cuttings population in the two packaging methods were calculated based on 365 cuttings and it shows that the cuttings characteristics of the two methods are similar and the differences are insignificant (Table 5).

For the calculation of the critical weight, the mean, standard deviation and CV values of *Lavateramaritima*in the modified method (Table 5) were used. In the modified method, the 'minimum quantity' package strategy was used for the nominal number of cuttings in a package (50 cuttings). The critical weight was calculated by applying Eq. 2. Table 6 presents the descriptive statistics of package size in both methods. The results indicate that the range of the number of cuttings in a package (between the largest package to the smallest package) was reduced from 19, in the current method, to 8 in the modified method. The standard deviation and the CV were reduced by 30% and 33%, respectively. Moreover, the amount of packages containing cuttings below the nominal number (50) and the farmer's strategy (minimum of 54 cuttings) were 5% and 30%, respectively, in the current method. The amount of packages containing cuttings below the nominal number was reduced to zero with the modified method.

Figure 4 illustrates the distributions of package size in the current and modified methods respectively.

4. Conclusions

The goal of every manufacturer is to pack the specified nominal quantity in each package, while incurring minimum cost. Products with high weight variability must be packed manually because, in general, automatic weighing scales are utilized only in packing products with very low weight variability.

An innovative method for packing 'packages labelled by count' was presented. A mathematical model to support the preparation of such packages by means of a weighing procedure was developed on the basis of the definition and characteristics of the coefficient of variation (CV) of the product weight. It uses the product CV in order to determine the critical package weight and to comply with the package definitions.

The experiment results revealed that the variability of the package size was high when counting manually, even when the packages nominal number was relatively low. The modified method which involves weighing procedure of 'packages labelled by count' reduced the variability in package size and minimized to zero the under filling of packages.

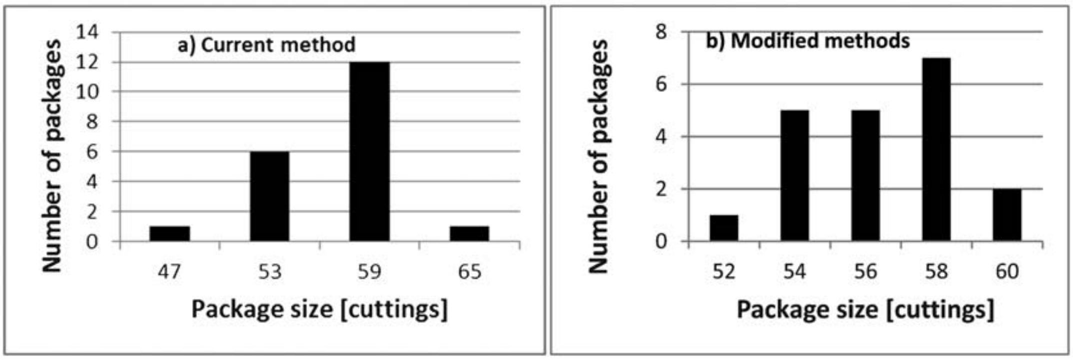
The procedure can be utilized as a management tool by farmers to determine the package characteristics, the

Table 5: Descriptive statistics of cuttings population in the two packaging methods

Method	Mean [g]	S.D. [g]	CV	*n*	Min [g]	Max [g]
Current	0.503	0.167	0.333	214	0.17	0.98
Modified	0.505	0.172	0.341	151	0.18	0.99

Table 6: Descriptive statistics of package size in both methods

Method	Mean	S.D.	CV	N	Min	Max
Current	54	3.29	0.0610	20	45	64
Modified	55.8	2.28	0.0409	20	52	60



(a) (b)

Figure 4: Package size distribution of a) current and b) modified methods

working instructions for preparation of packages, and to satisfy given commercial constrains at minimum costs.

About the authors

Avital Bechar is a Senior Research Scientist in the Institute of Agriculture Engineering, Agriculture Research Organization and the head of the Agricultural Robotics Lab. He holds a B.Sc. degree in Aerospace Engineering and a M.Sc. degree in Agricultural Engineering, both from the Technion, Haifa, Israel, and a Ph.D. degree in Industrial Engineering from Ben-Gurion University, Beer Sheva, Israel. His research interests are robotics in agriculture, human-robot systems, and industrial engineering methods for agricultural production systems.

Dr. Bechar is a member of the EurAgEng and CIGR, Societies for Engineering in Agricultural, Food and Biological Systems and a member of the IEEE SMC, the IEEE Robotics and Automation Society.

Gad Vitner is a Professor of Industrial and Systems Engineering at the School of Engineering in Ruppin Academic Center. He obtained a Ph.D. in Industrial and Systems Engineering from University of Southern California in Los-Angeles in 1981. He received both his B.Sc. and M.Sc. in Industrial Engineering and Management at the Technion in Haifa. He started his professional career as a lecturer at Ben-Gurion University and after 3 years joined industry where he served for 15 years in various managing positions in several organizations. In 1999 he joined the School of Engineering at Ruppin Academic Center as head of Industrial Engineering and Management Department and since 2005 serves as Dean. His research interests are: Operations Management, Service Management, Project Management, Quality Management and Production Planning and Control.

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