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RESEARCH PAPER: 2001-7

**COST-BENEFIT ANALYSIS OF INVESTMENT
IN RESEARCH ON ABSCISSION
CHEMICALS**

BY

Mark G. Brown

Senior Research Economist

FLORIDA DEPARTMENT OF CITRUS

Economic and Market Research Department

P.O. Box 110249

Gainesville, Florida 32611-2049 USA

Phone: 352-392-1874

Fax: 352-392-8634

Email: mgbrown@ufl.edu

www.floridajuce.com

Cost-Benefit Analysis of Investment in Research on Abscission Chemicals

Introduction

The purpose of abscission research is to develop a agent that will enhance the separation of citrus fruit from trees and increase the recovery rates of mechanical harvesting systems. In addition to the early and midseason orange crop, the abscission agent would be expected to be used in harvesting much of the Valencia orange crop.¹

A key parameter for the abscission agent to be cost effective is the recovery rate which is defined in this study as the amount of fruit harvested by a mechanical system divided by the amount that could have alternatively been harvested by hand.

This study focuses on the marginal costs and benefits of using the abscission agent to increase mechanical harvesting recovery rates. Increasing the recovery rate straightforwardly provides benefits through the earnings obtained from the additional fruit recovered. Additionally, mechanical harvesting costs, including the costs of the abscission agent, are expected to be significantly lower than manual harvesting costs.

In the following sections, formulas for a marginal cost/benefit analysis are developed and then applied in analyzing a hypothetical situation. The analysis is based on the assumption that mechanical harvesting research will succeed in developing a cost-effective harvesting system that will eventually be widely used. Without the abscission agent, mechanical harvesting is assumed to be used to harvest the early-and-midseason-orange crop. With the abscission agent, mechanical harvesting is assumed to be used to harvest both the early-and-midseason-orange crop and a large part of the early Valencia crop.²

There is a cost of configuring acreage for mechanical harvesting (appropriate tree spacing, density, pruning and skirting). At the time when the abscission agent becomes available for use, sufficient early and midseason orange acreage may be configured appropriately for mechanical harvesting to be viable. Valencia acreage may also be appropriately configured. If this is not the case, the additional cost of configuring early and midseason orange and/or Valencia trees needs to be considered.

¹ After the first month or two of the Valencia season, the grip between Valencia oranges and tree stems tends to become stronger, and a primary use of the abscission agent would be in harvesting Valencia oranges. At harvesting, Valencia trees have two crops—the current season's crop and the next season's crop of developing fruit. Abscission agents would make it easier to remove the current season's crop without harming the next season's crop.

² There may also be a possibility that the abscission agent can be used to harvest other citrus.

In addition, the cost of registering an abscission agent with the Federal Government may be significant and should be considered in making a final judgment on providing abscission research funding.

Cost-Benefit Model

This section shows the formulas used to calculate the stream of expected net returns resulting from the use of an abscission agent. These returns are then compared to the costs involved.

I. On-tree Revenue (R_1) for Manual Harvesting

$$(1a) \quad R_1 = (p - c_1 - c_3) * q ,$$

or

$$(1b) \quad R_1 = op_1 * q ,$$

where

q = boxes harvested manually,

p = delivered-in price per box,

c_1 = pick and roadside cost per box based on current manual picking,

c_3 = haul cost per box, and

$op_1 = p - c_1 - c_3$ is the on-tree price for manual harvesting.

II. On-tree Revenue (R_2) for Mechanical Harvesting Not Adjusted for Abscission Costs

$$(2a) \quad R_2 = (p - c_2 - c_3) * r_2 * q ,$$

or

$$(2b) \quad R_2 = op_2 * r_2 * q ,$$

where

r_2 = the percentage of boxes recovered by the mechanical harvesting system without abscission,

$r_2 * q$ = boxes harvested by mechanical harvesting without abscission,

c_2 = pick and roadside cost per box based on mechanical harvesting system (the cost of the machine, fuel, labor, etc.)³, and

$op_2 = (p - c_2 - c_3)$ is the on-tree price for mechanical harvesting without abscission.

³ Extending mechanical harvesting to Valencia oranges would decrease the cost per box of mechanical harvesting c_2 by spreading out the fixed capital costs across both early and midseason and Valencia oranges.

III. On-tree Revenue (R_3) for Mechanical Harvesting Adjusted for Abscission Costs

$$(3a) \quad R_3 = (p - c_2 - c_3 - c_a / r_3) * r_3 * q ,$$

or

$$(3b) \quad R_3 = op_3 * r_3 * q ,$$

or

$$(3c) \quad R_3 = (p - c_2 - c_3 - c_a / r_3) * [r_2 + (r_3 - r_2)] * q ,$$

or

$$(3d) \quad R_3 = R_2 + [(p - c_2 - c_3)(r_3 - r_2) - c_a] * q ,$$

where

r_3 = the percentage of boxes recovered by the mechanical harvesting system with abscission,

c_a = the cost per box of the abscission agent plus the cost per box of applying the agent to trees (spray equipment, labor, etc.), and

$op_3 = p - c_2 - c_3 - c_a / r_3$ is the on-tree price adjusted for abscission costs.

IV. Benefits of Mechanical Harvesting Without Abscission

For mechanical harvesting without abscission to be economical, the on-tree revenue for this type of operation needs to be greater than that for manually harvesting, or, formally

$$(4a) \quad R_2 > R_1 ,$$

or

$$(4b) \quad op_2 * r_2 > op_1 .$$

Let the gain in revenue or benefits due to mechanical harvesting without abscission be

$$(5a) \quad B_m = R_2 - R_1$$

or

$$(5c) \quad B_m = (op_2 * r_2 - op_1) * q ,$$

or

$$(5d) \quad B_m = [(p - c_2 - c_3) * r_2 - (p - c_1 - c_3)] * q ,$$

or

$$(5e) \quad B_m = [c_1 - c_2 - (p - c_2 - c_3) (1 - r_2)] * q .$$

The term $c_1 - c_2$ is the cost advantage (the decrease in pick and roadside costs per box) of using mechanical harvesting compared to manual harvesting.

The term $(p - c_2 - c_3) (1 - r_2)$ is for the revenue loss due to less than 100% recovery by mechanical harvesting.

For example, assume $p = \$6.50/\text{box}$; $c_1 = \$1.50/\text{box}$; $c_2 = \$1.00/\text{box}$; $c_3 = .50/\text{box}$; $r_2 = .92$; and $q = 70$ million boxes. In this case, we have

$$B_m = [\$1.50 - \$1.00 - (\$6.50 - \$1.00 - .50)(.08)] * 70 \text{ million},$$

or

$$B_m = \$7.00 \text{ million}.$$

IV. Abscission Benefits

For an abscission agent to be economical, the on-tree revenue for citrus that is mechanically harvested using the abscission agent needs to be greater than that for citrus mechanically harvested without using the abscission agent, or, formally

$$(6a) \quad R_3 > R_2 ,$$

or

$$(6b) \quad op_3 * r_3 > op_2 * r_2 .$$

or from equation (3d)

$$(6c) \quad (p - c_2 - c_3)(r_3 - r_2) > c_a .$$

Let the gain in revenue or benefits due to abscission be

$$(7a) \quad B_a = R_3 - R_2$$

or, based on results (3d) and (6e),

$$(7b) \quad B_a = [(p - c_2 - c_3)(r_3 - r_2) - c_a] * q .$$

The term $(p - c_2 - c_3)(r_3 - r_2)$ is the revenue gain per box resulting from the increase in the recovery rate due to the abscission agent. This term minus c_a is the net revenue gain per box.

Continuing with the above example ($p = \$6.50/\text{box}$; $c_1 = \$1.50/\text{box}$; $c_2 = \$1.00/\text{box}$; $c_3 = .50/\text{box}$; $r_2 = .92$; and $q = 70$ million boxes), further assume $c_a = \$.10/\text{box}$ and $r_3 = .95$. In this case, we have

$$B_a = [(\$6.50 - \$1.00 - .50)(.03) - \$.10] * 70 \text{ million,}$$

or

$$B_a = \$3.50 \text{ million.}$$

Together the benefits of mechanical harvesting and the abscission agent for this example are $B_m + B_a = \$7.00 \text{ million} + \$3.50 \text{ million} = \$10.50 \text{ million}$. In this case, we consider both B_m and B_a to be benefits of the abscission agent assuming the Valencia orange crop could not be mechanically harvested without use of the abscission agent.

V. Breakeven Abscission Costs

The cost of the abscission agent and spray program that would make the on-tree returns using abscission equal to the manually harvested on-tree returns is

$$(8a) \quad c_a^b = (p - c_2 - c_3)(r_3 - r_2)$$

or

$$(8b) \quad c_a^b = c_a + B_a/q.$$

Result (8a) is found by setting B to zero in (7b) and solving for c_a ; result (8b) is found by solving (7b) for $(p - c_2 - c_3)(r_3 - r_2)$.

VI. Discounting Benefits

Over time the abscission agent is expected to generate a stream of benefits. Let B_{an} be the benefit in period n , i.e., we are attaching a time subscript n to the benefits as specified by equation (7b).

Assume the abscission agent will be available k_1 years in the future and can be used for the next k_2 years. Then, the present discounted value (PDV) of the benefits is

$$(9) \quad \text{PDV} = \sum_{n=k_1 \text{ to } (k_1+k_2)} B_{an}/(1+i)^n,$$

where i is the discount rate. (Instead of B_a , B_m and/or $B_m + B_a$ might be discounted using equation (9), depending on the analysis, where as defined above B_a , B_m and $B_m + B_a$ are the on-tree benefits for abscission, for mechanical harvesting, and mechanical harvesting and abscission, respectively.)

Assuming $B_{an} = B_a$; i.e., the same benefit in each year, we have

$$(10a) \quad PDV = B_a \sum_{n=k_1 \text{ to } (k_1+k_2)} 1/(1+i)^n,$$

$$(10b) \quad PDV = B_a [1/(1+i)^{k_1}] \sum_{n=0 \text{ to } k_2} 1/(1+i)^n.$$

If the abscission agent provides benefits forever; i.e., $k_2 = \infty$, we have

$$\begin{aligned} (10c) \quad PDV &= B_a [1/(1+i)^{k_1}] \sum_{n=0 \text{ to } \infty} 1/(1+i)^n \\ &= B_a [1/(1+i)^{k_1}] (1+i)/i. \\ &= B_a * D, \end{aligned}$$

where we define the discount factor $D = [1/(1+i)^{k_1}] (1+i)/i$. For example, if $k_1 = 3$ and $i=5.5\%$, then $D = 16.3$. Note that i and D are inversely related. Also note that when k_2 is less than infinity but large, the error in using $D = [1/(1+i)^{k_1}] (1+i)/i$, as opposed to $\sum_{n=k_1 \text{ to } k_2} 1/(1+i)^n$, is small. Hence, for our initial analysis, we use D for discounting.

Benefits Versus Costs

We need to compare the stream of benefits to the sum of the abscission research costs (C_1), the registration costs (C_2), and the costs of configuring acreage for mechanical harvesting (C_3). We assume the C_1 , C_2 and C_3 are appropriately discounted. For the investment in abscission agents to be cost effective, we need the above PDV to exceed $C = C_1 + C_2 + C_3$, i.e.,

$$(11a) \quad PDV > C,$$

$$(11b) \quad B_a > C/D.$$

Changing (11b) to an equality, dividing both sides of this result by q , and substituting c_a^b - c_a for B_a/q , based on(9), we find after rearranging terms

$$(12) \quad c_a^b = c_a + C/D/q,$$

which indicates that the breakeven price can also be considered that price which covers both short-run costs c_a and long-run costs $C/D/q$.

The Gamble

The research may not succeed in developing an effective abscission agent or efforts to register the agent may fail and these possibilities should be factored into the decision process. Let w be the probability of success and $1-w$ the probability of failure. The benefits are PDV for a successful research project and zero if the project fails. Hence, the expected benefits are $w*PDV+(1-w)*0$ or $w*PDV$. For the project to be funded we need

$$(13a) \quad w*PDV > C.$$

In general, the probability of success may vary across recovery rates. Consider the case for Valencia oranges where the choice is between manual harvesting versus mechanical harvesting with abscission, that is, Valencia oranges cannot be mechanically harvested without the abscission agent. Let PDV_r be the benefits when the recovery rate is r , and w_r be the probability of achieving r and hence PDV_r . For this case, equation (13a) can be written as

$$(13b) \quad \sum_r w_r * PDV_r > C,$$

where $\sum_r w_r = 1$ and $PDV_r = 0$ if the on-tree revenue from manual harvesting is greater than that for mechanical harvesting with an abscission agent, that is, the abscission/mechanical harvesting system is not used if it fails to reduce the harvesting cost below that for manual harvesting.⁴

Application

In this section, the above formulas are applied in analyzing the costs and benefits of mechanically harvesting hypothetical early and midseason, and Valencia orange crop using an abscission agent.

Table 1 shows the calculation of benefits (B) and associated discounted benefit streams (PDV), based on a D value of 8.3 (10% interest rate), for alternative recovery rates.

Following equation (7b), we calculated annual benefit ($B_m + B_a$) for Valencia oranges at \$10.50 million dollars for a 95 % recovery rate. Further assuming the abscission agent increases the recovery rate for early and midseason from 91% (obtained without using the abscission agent) to 95%, the annual benefit (B_a) for early and midseason oranges is \$5.20 million--- the recovery rate increases 4%, so that for an assumed crop of 130 million boxes an additional 5.2 million boxes ($.04*130$) are harvested; given an on-tree price for mechanical harvesting (2b) of \$3.50/box, the on-tree revenue for the additional 5.2 million boxes is \$18.20 not accounting for the cost of the

⁴ We are assuming PDV is a random variable with a discrete probability distribution. Formally, let $PDV_r = D*B_r$, where $B_r = R_{3r} - R_{1r}$, and B_r , R_{3r} and R_{1r} are the associated benefit and revenues when the recovery rate is r ; and let $B_r = R_{3r} - R_{1r}$ if $R_{3r} > R_{1r}$, otherwise (i.e, when $R_{3r} \leq R_{1r}$) $B_r = 0$; and $Pr(B_r) = w_r$.

abscission agent; assuming an abscission cost of \$.10/box for illustrative purposes, abscission costs are \$13.0 million (\$.10/box times 130 million boxes) and the on-tree revenue net of abscission costs is 5.2. Aggregating the Valencia and early and midseason results, the total orange benefits are \$15.70 for a 95% recovery rate. The associated stream of discounted benefits is \$255.91 million. The breakeven price is \$.18/box. Note that to obtain positive benefits, the recovery rates for early and midseason, and Valencia oranges must exceed 93% and 92%, respectively. Also, note that, given a total given a total orange crop of 200 million boxes, each penny change in the abscission cost per box is equivalent to a \$2 million change in net on-tree benefits (B) and a \$32.6 million change (2×16.3) in the present discounted value of the stream of net benefits (PDV).

Table 2 also shows expected values associated with Table 1. These expected values can be used to further judge whether the expected benefits of developing an abscission agent will cover the expected costs. For example, if one feels the likelihood is 1 out of 4 or 25% of developing or successfully registering an effective abscission agent that yields a 95% recovery rate, the expected discounted stream of benefits, unadjusted for abscission harvesting costs, is \$145.5 million. In this case, to carry on with research on abscission, the sum of abscission harvesting costs, abscission research costs, registration costs and costs of configuring acreage for mechanical harvesting ($c_a \times q \times 16.3 + C1 + C2 + C3$) should be less than \$145.5 million.

More realistically, there may be a range of possible recovery rates obtained from use of an abscission agent. Assume that an abscission agent has a 50% chance of improving recovery rates over the 94%-97% range, and let the probabilities of the abscission agent resulting in 94%, 95%, 96% and 97% recovery rates be 20%, 15%, 10% and 5%, respectively. Then, applying (13b), the expected stream of benefits is \$187.37 million---for $w=1\%$, the $E(PDV)$ is \$4.5, \$5.8, \$7.1 and \$8.4 million for the 94%, 95%, 96% and 97% recovery rates, respectively, so that for the assumed values of w in this example, we have the overall $E(PDV) = 20 \times \$4.5 + 15 \times \$5.8 + 10 \times \$7.1 + 5 \times \$8.4 = 290.96$ million. Again, this result is not net of abscission harvesting costs.

These results indicate the importance for decision makers to not only have accurate estimates of prices and costs for this problem but to also form subjective estimates of the probabilities of success or failure of the research.

Another example showing possible costs and benefits of using an abscission agent is shown in Tables 3 and 4. In these tables, the pick and roadside cost for mechanical harvesting (c_2) is assumed to be higher at \$1.25 per box and a small cost saving for manual harvesting citrus loosened by the abscission agent is assumed. Scenarios showing estimated benefits for using the abscission agent to harvest early and midseason oranges and Valencia oranges are provided. These estimated benefits are not net of abscission costs, as we do not make assumptions of the costs of the abscission agent and its application.

Table 1. Illustrative example of the effects of the recovery rate on abscission benefits.

Recovery Rate	Potential Crop (100% Recovery)	Recovered Crop	Delivered-In Price	Pick & Roadside Cost		Haul Cost	Hypothetical Abscission Cost	Manual On-Tree	
				Manual	Mechanical Harvesting			Price	Revenue
r	q	r*q	p	c1	c2	c3	ca	p-c1-c3	R1=q*(p-c1-c3)
- % -	-- million boxes -			----- dollars per box -----					- mil. \$ -
89	70.0	62.6	6.20	1.50	1.00	.50	.10	4.20	294.0
91	70.0	63.7	6.20	1.50	1.00	.50	.10	4.20	294.0
93	70.0	65.1	6.20	1.50	1.00	.50	.10	4.20	294.0
95	70.0	66.5	6.20	1.50	1.00	.50	.10	4.20	294.0
97	70.0	67.9	6.20	1.50	1.00	.50	.10	4.20	294.0
99	70.0	69.3	6.20	1.50	1.00	.50	.10	4.20	294.0

Recovery Rate	Mechanical On-Tree		Abscission Cost	Mechanical Minus Abscission Cost On-Tree Revenue	Annual Benefits	Discounted Stream of Benefits	Breakeven Abscission Cost ^a
	Price	Revenue					
r	p-c2-c3	R2=r*q*(p-c2-c3)	ca*q	R3=R2-ca*q	B=R3-R1	PDV=8.3*B	(R2-R1)/q
- % -	- \$/box -			----- million \$ -----			- \$/box -
89	4.70	294.0	7.0	287.0	-7.0	-58.1	.00
91	4.70	299.4	7.0	292.4	-1.6	-13.4	.08
93	4.70	306.0	7.0	299.0	5.0	41.3	.17
95	4.70	312.6	7.0	305.6	11.6	95.9	.27
97	4.70	319.1	7.0	312.1	18.1	150.5	.36
99	4.70	325.7	7.0	318.7	24.7	205.1	.45

^aAssumes that the recovery rate will be 89% with mechanical harvesting and no abscission.

Table 2. Expected values

Recovery Rate	Expected Value			
	Benefit: $E(PDV) = w \cdot PDV$			
r	w = .75	w = .50	w = .25	w = .01
- % -				
89	-43.6	-29.1	-14.5	-0.6
90	-30.5	-20.3	-10.2	-0.4
91	-10.0	-6.7	-3.3	-0.1
92	10.5	7.0	3.5	0.1
93	30.9	20.6	10.3	0.4
94	51.4	34.3	17.1	0.7
95	71.9	47.9	24.0	1.0
96	92.4	61.6	30.8	1.2
97	112.9	75.2	37.6	1.5
98	133.3	88.9	44.4	1.8
99	153.8	102.5	51.3	2.1

Total Crop Available for Harvesting (100% Recovery)
Potential Share of Crop Mechanically Harvested (100% Recovery)
Potential Boxes Mechanically Harvested (100% Recovery)
Remaining Boxes Manually Harvested (100% Recovery)

[illegible]

Footnotes for Table 3:

- (a) The table is set up to analyze other assumed recovery rates; for some assumed rates a column result may not be applicable; negative benefits set to zero.
 (b) Average (rounded) on-tree price from 1996-97 through 2000-01.
 (c) Assumes no abscission costs at this point; adjusted for abscission costs subsequently.
 (d) Productivity and reduced wage assumptions:

Pick Costs Assumptions					
Labor					
Productivity	Piece Rate	Min. Wage	Act. Wage		
Boxes/hr.	\$/box	\$/hr.	\$/hr.	\$/Box	
6.0	0.70	4.20	5.15	0.86	
6.6	0.70	4.62	5.15	0.78	
7.2	0.70	5.04	5.15	0.72	
7.8	0.70	5.46	5.15	0.70	
8.4	0.70	5.88	5.15	0.70	
9.0	0.70	6.30	5.15	0.70	
9.6	0.70	6.72	5.15	0.70	
10.2	0.70	7.14	5.15	0.70	

Pick Costs Without Abscission					
Scenario A					
Crop	% Total	Labor Productivity	Wage		
Mil. Boxes		Boxes/hr	Mil. Hrs.	\$/hr	\$/Box
38.3	17%	6.0	6.4	5.15	32.9
38.3	17%	6.6	5.8	5.15	28.9
38.3	17%	7.2	5.3	5.15	27.4
38.3	17%	7.8	4.9	5.46	26.8
38.3	17%	8.4	4.6	5.88	26.8
38.3	17%	9.0	4.3	6.30	26.8
38.3	17%	9.6	4.0	6.72	26.8
230.0	100%	7.36	31.3	5.46	170.7

Pick Costs With Abscission					
Scenario B					
Crop	% Total	Labor Productivity	Wage		
Mil. Boxes		Boxes/hr	Mil. Hrs.	\$/hr	\$/Box
38.3	17%	6.6	5.8	5.15	29.9
38.3	17%	7.2	5.3	5.15	27.4
38.3	17%	7.8	4.9	5.46	26.8
38.3	17%	8.4	4.6	5.88	26.8
38.3	17%	9.0	4.3	6.30	26.8
38.3	17%	9.6	4.0	6.72	26.8
230.0	100%	7.97	28.9	5.71	164.7
Gain in Productivity vs scenario A					
		8%			0.72

Scenario C					
Crop	% Total	Labor Productivity	Wage		
Mil. Boxes		Boxes/hr	Mil. Hrs.	\$/hr	\$/Box
38.3	17%	7.2	5.3	5.15	27.4
38.3	17%	7.8	4.9	5.46	26.8
38.3	17%	8.4	4.6	5.88	26.8
38.3	17%	9.0	4.3	6.30	26.8
38.3	17%	9.6	4.0	6.72	26.8
38.3	17%	10.2	3.8	7.14	26.8
230.0	100%	8.58	26.8	6.03	161.6
Gain in Productivity vs scenario A					
		17%			0.70

- (e) Not adjusted to the possibility that mechanical harvesting benefits with abscission (unadjusted for abscission costs) are less than manual harvesting benefits with abscission (unadjusted for abscission costs).
 (f) If mechanical harvesting benefits with abscission (unadjusted for abscission costs) are less than manual harvesting benefits without abscission, all boxes are manually harvested with abscission.

Table 4. Summary Results in Table 3.

Recov. W/O Mech. Harv.	Early and Mideseason										
	93%										
	Recovery With Mechanical Harvesting										
	93%	93%	93%	93%	94%	95%	96%	97%	98%	99%	100%
Potentail % Mech. Harv.	On-Tree Benefits Unadjusted for Abscission Costs										
	\$Million/Yr										
10%	3	3	3	3	3	3	4	4	5	5	5
30%	3	3	3	3	3	3	4	6	7	8	10
50%	3	3	3	3	3	3	6	8	10	12	14
75%	3	3	3	3	3	4	7	10	14	17	20
100%	3	3	3	3	3	4	9	13	17	22	26
											30
Valencia											
	Recovery With Mechanical Harvesting										
	93%										
	On-Tree Benefits Unadjusted for Abscission Costs										
	93%	93%	93%	93%	94%	95%	96%	97%	98%	99%	100%
Potentail % Mech. Harv.	\$Million/Yr										
10%	4	4	4	4	4	4	4	4	5	5	6
30%	4	4	4	4	4	4	4	5	6	7	9
50%	4	4	4	4	4	4	4	5	7	10	12
75%	4	4	4	4	4	4	4	6	9	13	16
100%	4	4	4	4	4	4	4	6	11	16	20
											25
Total Oranges											
	Recovery With Mechanical Harvesting										
	93%										
	On-Tree Benefits Unadjusted for Abscission Costs										
	93%	93%	93%	93%	94%	95%	96%	97%	98%	99%	100%
Potentail % Mech. Harv.	\$Million/Yr										
10%	7	7	7	7	7	7	7	8	9	10	11
30%	7	7	7	7	7	7	8	10	13	16	19
50%	7	7	7	7	7	7	10	13	17	22	26
75%	7	7	7	7	7	8	11	16	23	30	36
100%	7	7	7	7	8	8	13	19	28	37	46
											55