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CONTENTS

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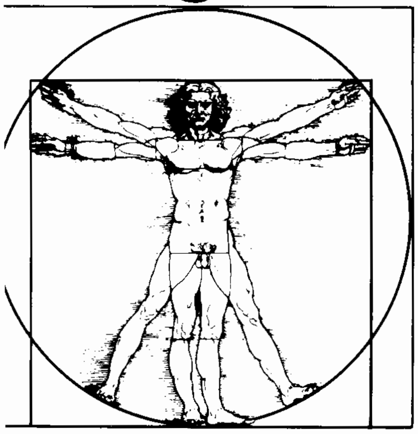

MANAGEMENT OF HUMAN SYSTEMS—
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HUMAN MANAGEMENT OF SYSTEMS—
the art of management, linking human beings into teams and catalyzing their full creative potentials through enterprise and leadership

Decision tools to benefit children needing adoption

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Abstract. Millions of children worldwide need permanent families. But traditional paper based methods, disagreements between agencies, and excessive nationalistic restrictions keep many children apart from potential parents able and eager to nurture them.

This paper focuses on the use of Weighted Ordered Weighted Averages and linear assignment programming for matching orphaned or abandoned children with adoptive families. Traditional paper based, one-child-at-a-time approaches are slow, and speed matters, because of the well documented harm done when children spend too much time waiting. Our focus is on simultaneous matching in which a pool of potential families is viewed as a resource to be used of the benefit for a pool of children in a global way rather than one at a time. A special case of the Weighted Ordered Weighted Average, designed to be transparent to social workers with little or no mathematical training or inclination, is used to aggregate criteria.

The United States Department of Health and Human Services estimates that over 500,000 children are in foster care with 130,000 available for adoption [6]. In sub-Saharan Africa, Asia, Latin America, and the Caribbean, a joint report by the UN/AIDS/UNICEF/USAID estimates that in 2003 there were 143 million orphans [24]. Negative experiences with the foster care system also lead to more children available for adoption [8,10,15,16]. Furthermore, with the rapid increase in drug dependency, AIDS, child maltreatment, and homelessness, the number of children available for adoption increases concomitantly [1]. It is universally agreed that a more efficient and swifter system needs to be developed in order to place these children in permanent homes [2,14,17].

This paper focuses on the use of Weighted Ordered Weighted Averages [21] and linear assignment programming for matching orphaned or abandoned children with adoptive families. We begin by reviewing traditional paper based, one-child-at-a-time approaches using unaided human judgment or human judgment aided by semi-automated systems for preliminary screening and short-listing. The primary focus is on simultaneous matching in which a pool of potential families is viewed as a resource to be used for the benefit of a pool of children in a global way rather than one at a time. A special case of the Weighted Ordered Weighted Average, designed to be transparent to social workers with little or no mathematical training or inclination, is used to aggregate criteria.

Keywords: Ordered weighted average, aggregation, MCDM, adoption

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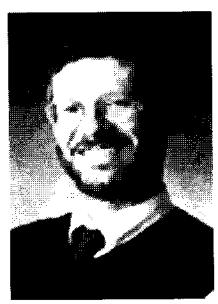

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1. Individual placement

Placement of individual children by informal methods is the traditional approach, and what is most commonly done [4]. The adoption worker finds a family for one child at a time and makes decisions one child at a time. The process happens in reverse as well. A prospective adoptive parent comes in seeking a child. This process entails each worker being familiar with numerous case files, and interviewing numerous prospective adoptive parents. There are obvious advantages and disadvantages: It is a very personal approach, but the worker can only handle a limited number of families. It is not humanly possible to mentally juggle all the available families simultaneously. As a result, the worker must inevitably use heuristics [9] to pre-screen the candidates down to a fairly arbitrary set of candidate families for the child under consideration.

Informal methods are slow, and speed matters, because of the things we know about the harm done to children who spend too much time in institutions waiting for a home.

Decision support systems can search a large data base of families to find a short list of potential placements for a child. So rather than evaluating the match between a child and a somewhat arbitrary sequence of families until one is found that is "good enough", [20] the child's match with every one of a systematically chosen short list of families is evaluated. Because the list is short and pre- selected using specified rules, the social worker can read all the dossiers, look at the pictures, telephone them. This method can give better quality than the purely informal system, but it is not necessarily faster because the worker will be looking at many dossiers for each child, and because they have been screened, fewer of them can be eliminated quickly. And the overall outcomes still depend on the order in which the children are considered, one at a time.

One example of this approach is the Christian Adoption Center website http://christianadoptioncenter.com/ in which a woman in a crisis pregnancy can enter a few parameters about what kind of family she wants her child to grow up in, and the system responds with information about those families in the database who best match these criteria. (The families are already pre-screened for general fitness to adopt; the matching is specifically on compatibility with the specific child in need.)

1.1. *The issue of importance weights*

The relative importance of various criteria for screening families and matching them to children [3,11] is an issue whose contentiousness has been an unnecessary hindrance to formalizing the adoption process and making it more transparent. However, because attributes tend to be correlated in clusters, it is better to spend resources on getting a moderately large number of attributes with an approximate importance rating of each one rather than on refining the importance weights for a smaller set of attributes. Appendix 1 gives a numerical example using ten families rated by two different agencies on seven dimensions of compatibility with one specific child. These separate sets of weights are multiplied by each family's percentage score on the corresponding dimension and summed to give two composite scores for each family, one for each of the two authorities.

The overall rating of each family is calculated using importance weights that come from two very different agencies; the resulting rank-ordering is not identical between authorities, but because of the correlation the ranking is not worthy of investing scarce resources and time-consuming argumentation about the question of which attribute is more important. If you consider many attributes it does not matter significantly which you consider of low or high, or of critical importance. Families which are high on some of your attributes tend to be high on others, and vice versa. In fact, they are going to come into clusters. For instance, access to medical care and access to education are going to be correlated with each other, so you don't have to argue about which is more important.

The robustness of the qualitative aspects of the overall assessment with respect to changes in the importance weights is closely related to the counterintuitive robustness of linear models in general documented by Dawes and Corrigan [5].

1.2. *Failure of individual placement approaches*

It is easy to document agenda effect [13,18] in which the order in which children are considered for placement can affect whether some children receive an appropriate placement at all. This is especially true if the "easiest" placements are considered first ("greedy algorithm") [12]. When the number of children and families under consideration at a time is small, the agenda effect can be overcome by diligence on the part of human decision makers, but when we try to address any reasonable fraction of the population of children without families, informal methods are totally inadequate.

When the number of children and the number of candidate families are both very small (in the single digits), it is possible for an experienced and conscientious social worker to become familiar with all of them and keep all the possibilities implicitly or explicitly in mind. Slightly larger groups can be handled using mental heuristics such as "chunking" [7].

But even a very modest increase in the number of children and families under consideration leads to information overload and mental fatigue. This is the inescapable reason that, before modern information technology, decisions had to be made essentially one at a time. A partial alternative is delegation; this requires a large number of people making decisions, with more people coordinating and overseeing them. This leads to large bureaucratic organizations, which are so slow as to counteract the potential speedup from dividing the workload [23].

It sounds very noble to say I going to devote myself to one child at a time, but the dark side of that means that you are ignoring all the other ones while you are concentrating on this one. Concentrating on one child at a time is for the families to do; they can do a better job than the institutions can.

Table 1 is a very simple two child, two family example. The numbers in the top part of the table represent some "soft" measure of how good the match is. According to this, the best possible match on an individual basis is child X with family 1, so that's where most people would start. But if you place child X with family 1, you must place child Y with family 2 which is not nearly so good a match. The assignment algorithm in linear programming provides the solution in which the sum of all the compatibility scores of selected matches is greatest, with no agenda effect.

Table 1

The one best match blocks the best overall match

Potential Match		Family 1	Family 2
	Child X	0.9	0.8
	Child Y	0.8	0.5
"Best first" Placement		Family 1	Family 2
	Child X	0.9	
	Child Y		0.5
			Average Match Quality 0.7
Simultaneous Placement		Family 1	Family 2
	Child X		0.8
	Child Y	0.8	
			Average Match Quality 0.8

The scores in the tables are treated as "soft" numbers. They are used by the assignment algorithm to make ordinal comparisons among global assignment sets based on the total of the scores of the constituent pairings. The chosen assignment set is then subject to human review.

2. Simultaneous placement by WOWA and assignment algorithm

This section presents a very small example of simultaneous matching between seven children and seven families. Table 2 shows a data base of children and a data base of potential adoptive families. A real system would use more attributes, but for illustrative purposes this one has the sex, age, country, time waiting for placement, and very crude measure of developmental handicap and physical handicap.

The child's country is included to illustrate the fact when populations of children in need of permanent placement are pooled, the agencies that currently have custody and responsibility for the children will differ in the criteria they want to apply to potential adoptive families. As a very simple illustration of how this might work, I assume that country A believes the ideal adoptive parents should be no older than 35, while Country B considers the ideal age range to go up to 40 years. (Later we will also make use of the fact that Country B is reluctant to release children for foreign adoption unless they have been waiting unsuccessfully for at least 12 months for a domestic placement to be found.)

Table 3 illustrates the process of calculating a "soft match score" for a particular pairing of a child with a family; in this case, we evaluate the desirability of matching Natasha with the Adams family. Since Natasha is a full two years older than the age the Adamses prefer, the match scores zero on age compatibility. Since the Adamses have no preference between boys and girls, the pairing scores 100% on gender compatibility The 2 under Developmental Handicap near the top of the table means that Natasha is severely handicapped in this area; the zero in the corresponding column for the Adams family indicates that they are not considered able (or do not consider themselves able) to deal with even a moderate developmental handicap. Thus, another zero compatibility score for this pairing. Natasha also has a moderate physical handicap, but the Adamses are well prepared to deal with this, so the compatibility is 100% on that item.

The Adamses are 45 years old, which is moderately outside what Country B (Natasha's country of origin) considers ideal, so the matching has a score of 50% on the criterion of parental age. This initial analysis is termed "Global" because the fact that the Adams family live in Country A and Natasha is in Country B is ignored.

Each of the criteria is given a relative weight to show its importance: 2 for Child Age, 2 for Sex, 3 for Developmental Handicap, 3 for Physical handicap, and 4 for Parent Age.

The last two inputs in the calculation of overall compatibility are the minimum and maximum of all the others. These values are used to implement the common sense notion that for a match to be a good one overall, the best characteristic of the match ought to be especially good, and the worst ought not to be very bad. In the example shown, the best criterion, with a value of $\max\{0, 1, 0, 1, 0.5\} = 1$, is given an additional weight of 4 in addition to the intrinsic importance of whatever attribute is best for pairing a particular family with a particular child, and the worst attribute, with a

Table 2

Child and family databases

	Child	Age (months)	Sex	Develop. handicap	Physical handicap	Months waiting	Nationality	Max parent age
1	Allen	3	M	0	0	1	A	35
2	Betty	12	F	1	0	4	A	35
3	Dmitri	6	M	0	1	7	B	40
4	Ekaterin	12	F	2	0	1	B	40
5	Ivan	24	M	1	1	5	B	40
6	Natasha	36	F	2	1	9	B	40
7	Pyotr	36	M	2	0	13	B	40
	Family	**Desired age**	**Desired sex**	**Acceptable develop. handicap**	**Acceptable physical handicap**	**Parent age**	**Nationality**	
1	Washington	1	M	0	0	35	A	
2	Adams	12	X	0	1	45	A	
3	Jefferson	24	X	1	0	30	A	
4	Madison	30	M	1	1	34	A	
5	Monroe	1	F	2	0	36	A	
6	Kruschev	12	X	0	2	39	B	
7	Gorbachev	24	F	1	0	42	B	

Table 3

Calculating a global soft match score

	Child	Age (months)	Sex	Develop. handicap	Physical handicap	Months waiting	Nationality	Max parent age	Wait for foreign adoption
6	Natasha	36	F	2	1	9	B	40	12
	Family	**Desired age**	**Desired sex**	**Acceptable develop. handicap**	**Acceptable physical handicap**	**Parent age**	**Nationality**		
2	Adams	12	X	0	1	45	A		
		Child age	**Sex**	**Develop. handicap**	**Physical handicap**	**Parent age**		**Minimum**	**Maximum**
		0	1	0	1	0.5		0	1
	Weight 47%	2	2	3	3	4		5	4

value of $\min\{0, 1.0.1, 0.5\} = 01$, is similarly given an additional weight of 5.

This approach is a compromise between two standard methods of multiple criterion decision making: Weighted sum, in which scores are multiplied times a measure of their relative importance and added together, and Elimination By Aspects [22], in which the one bad score on a single criterion is enough to eliminate a pairing regardless of how good it is on other considerations. The set of weights showing the intrinsic importance of the attributes are rescaled to add up to 1.0, and the values of the attributes are multiplied by these rescaled weights and added to provide a weighted average. Separately the two weights for the maximum and minimum are also rescaled to sum to 1, multiplied times the respective minimum and maximum values, and added to provided an Ordered Weighted Average [26]. Finally, the weighted average and the ordered weighted average are averaged together to find the "soft number" that, in relation to the soft number scores of all other possible pairings, gives an ordinal indication of how good this pairing is. This averaging method is mathematically equivalent to a special case of the Weighted Ordered Weighted Average [21], as described in Appendix 2.

In terms of the specific example, the match between Natasha and the Adams family is estimated as $[(\frac{2}{14} * 0 + \frac{2}{14} * 1 + \frac{3}{14} * 0 + \frac{3}{14} * 1 + \frac{4}{14} * 0 + \frac{4}{14} * 0.5) + ((\frac{5}{9}) * 0 + \frac{4}{9} * 1)]/2 = 47\%$. Since keeping Natasha in an institution until a better match is found is assigned a score of 50%, we know that Natasha will not end up with the Adams family.

Table 4 collects the estimated soft match scores for all 49 possible pairings between 7 children and 7 families, as well as the possibility of a child waiting in an institution for a better match and a family remaining on a waiting list.

2.1. *Greedy algorithm*

Table 5 gives the results of applying the "greedy" algorithm to this data base. The best individual match is between Allen and the Washington family at 97%, followed by the match between Ivan and the Madison family at 94% and Dmitri with the Kruschev fam-

Table 4

Global soft match scores for all possible child-family pairings

		Washington 1	Adams 0	Jefferson 3	Madison 4	Monroe 5	Kruschev 6	Gorbachev 7	(Institution)	(Institution)
Allen	1	97%	55%	69%	65%	63%	80%	49%	50%	50%
Betty	2	56%	53%	83%	60%	83%	75%	67%	50%	50%
Dmitri	3	79%	77%	68%	65%	58%	91%	52%	50%	50%
Ekaterin	4	51%	54%	77%	54%	84%	62%	74%	50%	50%
Ivan	5	54%	67%	80%	94%	53%	74%	56%	50%	50%
Natasha	6	42%	47%	72%	58%	60%	54%	69%	50%	50%
Pyotr	7	54%	47%	77%	79%	58%	54%	53%	50%	50%
(Wait list)		50%	50%	50%	50%	50%	50%	50%	50%	50%
(Wait list)		50%	50%	50%	50%	50%	50%	50%	50%	50%

Table 5

Results of greedy algorithm

		Washington 1	Adams 2	Jefferson 3	Madison 4	Monroe 5	Kruschev 6	Gorbachev 7	(Institution)	(Institution)
Allen	1	First								
Betty	2			Fifth						
Dmitri	3						Third			
Ekaterin	4					Fourth				
Ivan	5				Second					
Natasha	6							Sixth		
Pyotr	7		47%						50%	50%
(Wait list)			50%						50%	50%
(Wait list)			50%						50%	50%

Table 6

Results of global simultaneous matching

	Washington	Adams	Jefferson	Madison	Monroe	Kruschev	Gorbachev	(Institution)	(Institution)
Allen	Allen Washington								
Betty						Betty Kruschev			
Dmitri		Dmitri Adams							
Ekaterin					Ekaterin Monroe				
Ivan				Ivan Madison					
Natasha							Natasha Gorbachev		
Pyotr			Pyotr Jefferson						
(Waiting list)									(Wait list) (Institution)
(Waiting list)								(Wait list) (Institution)	

ily at 91%. The match of Ekaterin with the Monroe and the match of Betty with the Jeffersons are next, at 84% and 86% respectively. The next several matches in numerical order involve a child and/or a family that is already "taken", until we reach the match between Natasha and the Gorbachev family at 69% At this point, only Pyotr remains to be placed and only the Adams family is without a child, but at 47% the match between them is so poor that Pyotr is better off waiting in an institution for a better placement (scored at 50%).

2.2. *Global simultaneous assignment*

Table 6 shows the results of applying global simultaneous assignment ("linear programming") to the same set of soft match scores that the greedy algorithm was applied to. The method works by finding the assignments that maximize the sum of the scores of selected matches. This method finds a family for each child in the current data base, including Pyotr who is left without a family in the greedy algorithm.

2.3. *The next step*

The next step is not to pop the child onto an airplane, but to look at the dossiers for the selected pairs and see if these matches make sense. Not that they are necessarily the very best for this child, not that they are necessarily the very best for this family, but do they make sense.

If you have some doubts you can tell the computer "No you can't put this child here, try again". The total match score will never go up if you do that. Sometimes it will stay the same and you will say "OK, it didn't cost me anything". Sometimes the total match score will go down and either you say, "Oh, I see, if I don't allow that, then I am going to end up with some match that is really bad down the line, and so I am going to go back and follow the first print out". Or , you say "I know something the computer didn't know and I really don't want to go with that match".

2.4. *Implementation*

Simultaneous matching using the assignment problem of linear programming is old technology that has become very cheap and very prevalent. It used to be rather expensive, used by only large very well funded business, government, and military institutions. Now it can be used by anybody. A person with responsibility for the process of placing orphaned or abandoned children can go to the local Internet cafe anywhere in the world and find someone who can learn the method in a few days. They may be seventeen years old, they are going to need a lot of guidance from people who understand what the process is for, but the technology is cheap and prevalent.

Table 7
Results of assignment with nationality constraint

		Washington 1	Adams 2	Jefferson 3	Madison 4	Monroe 5	Kruschev 6	Gorbachev 7	(Institution)	(Institution)
Allen	1	97%	55%	69%	65%	63%	80%	49%	50%	50%
Betty	2	56%	53%	83%	60%	83%	75%	67%	50%	50%
Dmitri	3	0%	0%	0%	0%	0%	91%	52%	50%	50%
Ekaterin	4	0%	0%	0%	0%	0%	62%	74%	50%	50%
Ivan	5	0%	0%	0%	0%	0%	74%	56%	50%	50%
Natasha	6	0%	0%	0%	0%	0%	54%	69%	50%	50%
Pyotr	7	54%	47%	77%	79%	58%	54%	53%	50%	50%
(Wait list)		50%	50%	50%	50%	50%	50%	50%	50%	50%
(Wait list)		50%	50%	50%	50%	50%	50%	50%	50%	50%

	Washington	Adams	Jefferson	Madison	Monroe	Kruschev	Gorbachev	(Institution)	(Institution)
Allen	Allen Washington								
Betty					Betty Monroe				
Dmitri						Dmitri Kruschev			
Ekaterin							Ekaterin Gorbachev		
Ivan								Ivan (Institution)	
Natasha									Natasha (Institution)
Pyotr				Pyotr Madison					
(Wait list)			(Wait list) Jefferson						
(Wait list)		(Wait list) Adams							

The special weights for the attributes with the greatest and least compatibility build on a very sophisticated and recent mathematical theory of weighted ordered weighted averages, but this is quite transparent to the user, who only needs to understand the common sense concept that the best attribute ought to be very good and the worst attribute ought not to be too bad.

3. Nationality constraints

Now consider the issue of adoption within country versus outside of country. Today, many countries impose waiting periods upon children needing families until it is certain that there is no possible domestic placement for this particular child. The child can suffer severe developmental harm during this time of waiting. If there are 100 children and 50 domestic families, it can take a long time to identify any individual child as one who cannot possibly be placed domestically, even though it is certain that fifty children can only find a family internationally.

Table 7 shows the results of applying a requirement of Country B that no child is eligible for international adoption until he or she has spent 12 months in an institution waiting to see if a domestic placement becomes available. Of the five Country B children, only Pyotr satisfies this requirement; he is adopted by the Madison family in Country A, leaving the remaining four Country B children to compete for the two Country B families. The inevitable result is that two Country B children (in this case Ivan and Natasha) remain institutionalized.

Table 8

Simultaneous global assignment with weight given to nationality

		Washington 1	Adams 2	Jefferson 3	Madison 4	Monroe 5	Kruschev 6	Gorbachev 7	(Institution)	(Institution)
Allen	1	97%	60%	71%	67%	65%	83%	55%	50%	50%
Betty	2	61%	58%	83%	63%	84%	78%	71%	50%	50%
Dmitri	3	68%	66%	58%	54%	49%	92%	57%	50%	50%
Ekaterin	4	43%	46%	66%	46%	72%	64%	77%	50%	50%
Ivan	5	46%	58%	69%	81%	45%	77%	60%	50%	50%
Natasha	6	37%	41%	62%	49%	50%	59%	73%	50%	50%
Pyotr	7	59%	54%	80%	81%	62%	59%	58%	50%	50%
(Wait list)		50%	50%	50%	50%	50%	50%	50%	50%	50%
(Wait list)		50%	50%	50%	50%	50%	50%	50%	50%	50%

	Washington	Adams	Jefferson	Madison	Monroe	Kruschev	Gorbachev	(Institution)	(Institution)
Allen	Allen Washington								
Betty					Betty Monroe				
Dmitri						Dmitri Kruschev			
Ekaterin							Ekaterin Gorbachev		
Ivan				Ivan Madison					
Natasha									Natasha (Institution)
Pyotr			Pyotr Jefferson						
(Wait list)		(Wait list) Adams							
(Wait list)								(Wait list) (Institution)	

3.1. Compromise between global and national

Using pooled simultaneous matching, it is easy to make domestic adoption a plus factor among all the other considerations. A country that considers international placement a "last resort" will put a heavier weight on that consideration than a country that considers domestic placement merely desirable. In the hypothetical case of fifty domestic families and 100 children, the fifty domestic families will all get a child if they are qualified even if there are far more foreign families in the families database, but the other fifty children can also find homes, albeit abroad, quickly.

Table 8 illustrates this principle in the context of the seven child, seven family database. The rule of 12 months waiting in Country B before international adoption is treated as one more criterion like gender or age. As a result, the matches between the four Country B children who have not satisfied the waiting rule and Country A families is not zero as it was in Table 6, but it is less than it was in Table 4. As a result, only one Country B child, Natasha, is left without a permanent placement, and she has a much better chance than in Table 6 to be placed among the next group of prospective parents.

4. Conclusion

If the compatibility between a needy child and a willing family could be accurately measured on a single scale, the fact that there are so many orphaned and abandoned children and a large but limited pool of qualified families would still make the assignment

Table A1.1

Ten families rated by percentage on seven attributes

	Family 1	Family 2	Family 3	Family 4	Family 5	Family 6	Family 7	Family 8	Family 9	Family 10
1. Commited to parenting	80%	30%	100%	20%	15%	40%	55%	5%	0%	10%
2. Parenting skills	100%	80%	73%	53%	47%	67%	100%	0%	13%	60%
3. Medical access	92%	100%	46%	63%	100%	79%	54%	0%	79%	29%
4. Education access	67%	67%	50%	67%	100%	50%	33%	25%	33%	33%
5. Environment	100%	100%	0%	50%	50%	50%	50%	0%	50%	50%
6. Prior attachment	0%	100%	100%	0%	0%	0%	0%	100%	0%	0%
7. Genetic relation	50%	50%	100%	100%	0%	0%	0%	100%	50%	0%

process difficult and complex. In fact, even for a single child and a single family compatibility depends on a complex array of characteristics. Some characteristics are clearly .more important than others; nevertheless Zeleney [27] points out that "trade offs", in which each characteristic has a fixed importance weight and bad performance on some is easily outweighed by good performance on others, are a bad way to do business; clearly they are a worse way to meet the needs of vulnerable children. The use of weighed ordered weighted averages allows the importance weights to be tempered in two ways: credit is given to one "center of excellence" that can make a placement "beautiful" [27, p. 244ff], and extra weight on the worst characteristic of a match negates the "trade off effect" where a serious problem is masked by the averaging.

With appropriate decision science technology, child welfare agencies can get flatter, faster, and more agile organizations. This happened years ago in the business world. What this means is, the senior decision makers are going to be closer to the children. This may mean that some of the people that have gravitated to being senior decision makers now will go elsewhere and their places will be filled by people who want to be close to the children. And they will focus on exceptions instead of focusing on administration. A big organization, like it or not, requires a lot of administration. In a small organization, people can spend more time on what the organization is supposed to be accomplishing. Ideally, some of the middle managers, or at least their slots, would move into the front line, giving smaller case loads. Such an organization can move more rapidly and do at least as well in placements sooner. Speed matters.

Appendix 1. Issue of importance weights

Each percentage represents an objective or subjective assessment of that family's achievement of the objective relative to the difference between the best and worst achievement on that objective found in the actual database of families.

Table A1.2

Attribute importance weights rated differently by two different authorities

	Authority 1	Authority 2	Low	1
1. Committed to parenting	Critical	High	Medium	2
2. Parenting skills	Low	High	High	3
3. Medical	High	Medium	Critical	4
4. Education	Medium	Low		
5. Parenting environment	Medium	High		
6. Attachment	Low	Critical		
7. Genetic relation	Critical	Low		

Weights refer to the relative importance of the differences actually observed among the families in the database, not necessarily the absolute importance. For example, safety is of the utmost importance in air travel but of virtually no importance in choosing among equally safe major airlines.

These two authorities look quite different from each other in Table A1.2, but because the seven attributes are correlated, the families fall into clear clusters of three very attractive candidates (families 1, 2, and 3), four more "average" candidates (families 4, 5, 6, and 7), and three questionable candidates (families 8, 9, and 10). The key to this clustering is the use of a relatively large number of attributes, no one of which is considered an absolute.

Appendix 2. Additive WOWA

p_i, $1 \leqslant i \leqslant n$ are judgmental importance weights determined by the responsible agencies, each divided by the sum of those importance weights.

Table A1.3

Because attributes are correlated, importance weights do not make a major difference

	Rated by Authority 1		Rated by Authority 2	
	Score	Rank	Score	Rank
Family 1	12.3	1	11.4	3
Family 2	11.3	3	13.5	1
Family 3	12.1	2	11.6	2
Family 4	9.6	4	6.6	6
Family 5	7.1	5	6.4	7
Family 6	6.6	6	6.8	5
Family 7	6.5	7	7.6	4
Family 8	5.7	9	5.4	8
Family 9	6.2	8	4.3	10
Family 10	3.5	10	4.5	9

Derivation of ordered weights $\mathbf{w}_i$

L = judgmental importance weight to the idea that even the worst element of a good pairing shouldn't be too bad (maximin).

M = judgmental importance weight to the idea that a good pairing has at least one very strong element (maximax)

Strict Hurwicz criterion H:

$$H_1 = \frac{J}{L+M}, \qquad H_i = 0, \quad 1 < i < n,$$
$$H_n = \frac{M}{L+M},$$

where H_i is the weight given to the criterion whose satisfaction is the i'th largest.

The WOWA derived from this gives zero total weight to all but the lowest and highest. In case of ties, the result depends on the arbitrary choice of whch tied criterion is selected as the extreme.

Soft Hurwicz criterion:

$$w_1 = \frac{H_1 + \frac{1}{n}}{2}, \qquad w_i = \frac{1}{2n}, \quad 2 \leqslant i \leqslant n-1\ 1,$$
$$w_n = \frac{H_n + \frac{1}{n}}{2}.$$

The ordered weights for the soft Hurwicz criterion are the average of the weights for the strict Hurwicz criterion and those for equal weighting of all ranks.

Weighted Ordered Weighted Average

Interpolation function:

$$w^*(0) = 0,$$
$$w^*(x) = w_1 + \frac{x - \frac{1}{n}}{2} = \frac{H_1 + x}{2}, \quad 0 < \frac{i}{n} < 1,$$
$$w^*(1) = 1.$$

w^* is a monotone increasing function that interpolates the points $(\frac{i}{n}, \sum_{j \leqslant i} w_j)$.

WOWA weights

$p_{\sigma(j)}$ is the importance of the attribute whose value is j'th highest.

$$\omega_i = w^*\left(\sum^{i} p_{\sigma(j)}\right) - w^*\left(\sum^{i-1} p_{\sigma(j)}\right)$$

(Tora, 1997)

$$\omega_1 = w^*(p_{\sigma(1)}) = \frac{H_1 + p_{\sigma(1)}}{2},$$

$$\omega_i = \frac{H_1 + \sum^{i} p_{\sigma(j)}}{2} - \frac{H_1 + \sum^{i-1} p_{\sigma(j)}}{2}$$
$$= \frac{p_{\sigma(i)}}{2}, \quad 1 < i < n,$$

$$\omega_n = 1 - \frac{H_1 + \sum^{n-1} p_{\sigma(j)}}{2} = \frac{1 - H_1}{2}$$
$$+ \frac{1 - \sum^{n-1} p_{\sigma(j)}}{2} = \frac{H_n + p_{\sigma(n)}}{2}.$$

Thus, the WOWA weighting vector found using Tora's method is the average of:

(a) the importance weights arranged from the weight of the highest valued attribute to the lowest, and
(b) the strict Hurwicz weights H.

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